TOPICS OF THE MONTH

Heat losses—can we afford them?

HEAT transfer as a branch of applied science can be traced back to Wilhelm Nusselt, that remarkable and unassuming German engineer who died in 1957. Most people will remember Nusselt by the dimensionless number called after his name—this probably represents the greatest tribute to his memory. After graduating in 1906, Nusselt worked on heat technology with Knoblauch at Munich and the subject of his thesis was thermal conductivities of insulating materials. This, incidentally, was the first rigorous investigation of the subject. In Nusselt's method, which in the course of time was refined but never seriously altered, the appropriate Fourier differential equations were solved either by dimensional analysis or by series expansion. The most important paper of Nusselt on the ' Fundamentals of Heat Transfer ' was published in 1915 (*Gesundh.-Ing*, **38**, 477 and 490). In this work he derived fundamental equations using refined dimensional analysis. His most important equation, called the Nusselt equation, was for natural convection, and all equations for which he had experimentally evaluated the constants could be used to predict heat transfer under almost any laminar flow condition.

Naturally, the same laws governing promotion of heat transfer operate when a reduction in heat transfer is required. There are few people nowadays who will doubt the necessity of insulation in one of its many and various forms; however, when it comes to determination of the economics of this problem many factors are sometimes forgotten. The economic thickness of insulation for a pipe can be calculated by any of a number of methods each based on the determination of the thickness at which the sum of the insulation cost and the cost of the heat loss is a minimum. An example to illustrate this is given in ' Heat Insulation Manual ' published by W. Kenyon & Sons Ltd. Described in B.S. 1588 : 1949, the method is based on the fact that it is possible to calculate the total cost of insulation and heat loss for increasing thicknesses. If these results are then tabulated it will be found that the total cost decreases with thickness to a minimum and subsequently increases. For example, it is required to find the economic thickness of an insulation having a thermal conductivity 0.48 B.Th.U./sq.ft./hr./°F./in. thickness for a pipe 6½ in. o.d. at 500°F. It is assumed that the insulation is required to pay for itself within five years (40,000 hr.) with a fuel cost of 0.00004 pence/B.Th.U. The insulation cost, including application, can be estimated from commercial data for the following insulation thicknesses: 1 in., 1½ in., 2 in., 2½ in., 3 in. and 4 in. The heat loss from an insulated 6½-in. o.d. pipe can be determined from available graphs and the cost of heat loss thus calculated. By tabulating the individual costs the total cost can be estimated as follows:

Thickness of insulation, in.	*Cost of insulation/ ft. of pipe, in pence*	*Cost of heat loss/ ft. of pipe, in pence*	*Total cost in 40,000 h., in pence*
1	104.5	533.0	637.5
1½	128.25	413.0	541.25
2	154.25	333.5	487.75
2½	186.0	285.5	471.50
3	220.75	251.0	471.75
3½	257.0	224.0	481.0
4	296.75	206.5	503.25

Hence the minimum total cost appears at a thickness of 2½ in., which is termed the ' economic thickness '. We shudder to think how much money is lost annually in industry by failure to appreciate the significance of this factor!

It is, of course, inevitable that in industry, where both technical and commercial sections have to work side by side, it is often difficult for the commercial people to appreciate why thermal insulation is necessary—sometimes it is only installed in order to appease the plant engineer! This state of affairs could be rapidly altered if the total saving in heat were always calculated at the same time as the costs of insulation.

Modern trends in heat transfer theory and practice are analysing many factors that were previously never taken into account, as our special feature this month clearly demonstrates. It is probably no exaggeration to state that thermal losses represent not only financial losses, but also an inability to appreciate the principles so ably expounded by Fourier, Nusselt and their present-day heirs.

Careers in the chemical industry

SOME indication of the rapid rate of expansion of the chemical industry since the war was given recently by the Association of British Chemical Manufacturers. This vast growth can be shown in several ways. In 1959, for example, £160 million was invested in the industry compared with only £38 million in 1948. Furthermore, the industry's production is increasing at twice the rate of that of manufacturing industry generally. Thus the chemical industry has for some years retained the position of the country's third largest exporting industry. The measure of this increase in exports is shown by the fact that these have risen from a value of £82 million in 1948 to £293 million in 1959.

As a result of this increase in productivity the number of personnel employed in the chemical industry has not risen proportionally, and this is one of the main reasons that the A.B.C.M. has felt it necessary to publish a booklet on careers in the chemical industry. The main objective of this is to encourage young people leaving schools and universities to join the chemical industry and to make it their career. The booklet is tastefully designed and conveys some idea to the young reader of the nature of the chemical

industry whose diversity is probably not realised by those unacquainted with it. A large proportion of the publication is directed towards these ends as well as to indicating the key positions which this industry holds as a producer of raw materials for other major industries.

It is, of course, important that the chemical industry recruits young people into its ranks, and the sooner this is effectively done, the better. On the other hand, one wonders if this kind of propaganda is aimed at the right strata. To the grammar school boy who intends to study chemistry this is preaching to the converted. The boy who leaves school at 15 and wishes to learn a trade should be interested in such prospects; but is this really the material required by an industry that has to rely evermore on technological management?

New powder metallurgy technique

A CAREFULLY balanced dispersion of boron in stainless steel was recently obtained by an advanced powder metallurgy technique. Boron, due to its affinity for neutrons, is of vital interest as a flux attenuator in reactors. Its combination with stainless steel therefore offers a material which is strong, easily fabricated and resistant to corrosion and high temperatures. Despite many recent advances such as the use of vacuum fusion, alloys of boron and stainless steel suffer serious disadvantages. One major difficulty lies in the tendency of boron to ooze out of the alloy, especially during hot-working. This deboronisation drastically alters the neutron-capturing ability of the reactor material.

It must be appreciated that in nuclear technology uniformity of boron distribution in the stainless-steel carrier metal is of utmost importance. With conventional alloying procedures employed to date, boron could not be dispersed uniformly.

This new technique, which was developed by Chromalloy Corporation, permits the selection of optimum particle size and spacing of the neutron-absorbing constituent. Since capture of free neutrons depends on the spacing of boron nuclei, control over micro-structure allows more precise regulation of the pile. The new reactor material consists of boron or boron carbide uniformly dispersed in a matrix of stainless steel. The production is carried out as follows: Powdered constituents are weighed out, corresponding to the final composition desired. After special mills achieve homogeneity, the mixture is pressed into 'green' compacts or billets. During sintering, which takes place at a temperature below the melting point of any constituent, the metal particles bond into a solid, but porous composite. It is believed that at this stage the boron may actually alloy with the iron through diffusion. To eliminate all porosity, compacts are hot-worked. When fully densified, the composite is almost indistinguishable from its vacuum-melted and cast counterpart in its physical properties. However, analysis of the microstructure reveals that the material, unlike the cast alloy, is completely homogeneous; it has suffered little, if any, loss of boron.

Modern uses of ozone

THE bluish gas ozone forms a protective layer around the earth, extending from an altitude of 50,000 to 100,000 ft. The function of this gas is to filter out most of the harmful ultra-violet rays in sunlight. Turbulence in the atmosphere causes both the density and distribution of the gas to vary from time to time, thus modifying the amount of ultra-violet radiation. Since ozone cannot be packaged for commercial transportation, it must be manufactured on site. For this reason a large variety of ozonators have been developed for commercial purposes.

The first industrial ozonator was built by Siemens in 1857 on the discharge principle for ozone formation. Modifications of this unit have led to the prototype of present-day designs. All commercial ozonators are based on the principle of electric discharge through dielectrics, which act as stabilising resistances. It should be remembered that the ozonator has no moving parts and units have a life expectancy of about 25 years. Ozonators containing multiple units have been built in the United States with output up to 100,000 lb./day, as reported in a recent Battelle Memorial Institute report.

Such commercial generators are constructed with stainless steel tubes fastened into a stainless steel shell, which serves as a cooling jacket. A special glass dielectric is mounted concentrically in the centre of each tube. The glass dielectric tube is coated on the inside with an electrically conductive material. During operation dry air or oxygen passing through the annular space between the outside of the glass tube and the inner surface of the stainless steel tube is partially converted to ozone by a discharge across the annulus. For this conversion the current is increased to about 15,000 V. Manifolds placed at the ends of the ozonator can be employed to distribute the feed gas to the discharge spaces and to collect the ozonised gas. Either oxygen or air feed can be used for the production of ozone, and where tonnage oxygen is available it provides a particularly economical supply gas. It must be remembered that at the same power output about twice as much ozone is generated from oxygen as from air, so that electrical costs and equipment are greatly reduced when oxygen is used. However, in some operations the presence of oxygen in the final product is undesirable—in such cases air feed is likely to be a better choice.

The first important industrial use of ozone was as a germicide for water. More recently its use has been extended for the removal of impurities by means of oxidation. The world's largest ozone plant for the treatment of water is in use at the Belmont Water Treatment Plant in Philadelphia. From 1950 to 1955 an average of more than 10 billion gal. p.a. of presettled water from a local river were treated with ozone. The process involved diffusing ozonised air (containing 1.5 p.p.m. ozone) into water at a depth of about 18 ft. while it is in underground contact chambers. At maximum flow the theoretical contact time is about 10 min.

It is likely that the use of ozone may be helpful in solving problems associated with waste disposal. The powerful oxidising properties of ozone have been utilised for the destruction of phenols in coke-plant ammonia-still wastes and phenolic effluents from oil refineries. The neutralisation of industrial odours is another area in which ozone has proved effective—it has been used successfully for the abatement of the odours of sewage and fish in feed and fertiliser plants and for the control of paper-mill and commercial cooking odours. Probably the most important uses for ozone are in the production of carboxylic acids by ozonation of unsaturated olefines. Also of major importance is its use in liquid fuels, and more experience in handling potentially explosive liquefied gases is removing obstacles towards the use of ozone as a component in rocket fuels.

Industrial support for Fertiliser Programme

A PANEL of fertiliser industry representatives has recommended that the Food and Agriculture Organisation (F.A.O.) undertake a $2 million five-year programme, financed by the industry, to expand and improve the use of fertilisers in crop production. The panel was named by Mr. B. R. Sen, the Director-General of F.A.O., as a result of a meeting of industry representatives last April. Represented at the meeting were the International Potash Institute, the International Superphosphate Manufacturers' Association, the Centre d'Etude de l'Azote, and the Sulphur Institute.

Mr. H. Robin, representative of the Centre d'Etude de l'Azote and chairman of the panel, said that the intention is for the industry to make a firm commitment on the basis of figures reviewed at the meeting for the first two years of the programme's operation, with the understanding that if the programme develops to the satisfaction of all concerned, further support would be given for the following three years. The budget evolved by the panel, in collaboration with the F.A.O. secretariat, calls for expenditure of $350,000 in the first year and $450,000 in the second. The programme would make an annual contribution of $30,000 to the central operating fund of the Freedom-from-Hunger Campaign. In the course of the meeting the representatives drew up a suggested scale of contributions from various sectors of the fertiliser industry, which will be submitted to individual fertiliser associations and companies for their action.

The meeting said that the aim of the programme is to stimulate the interest of governments and farmers of less-developed countries in the efficient use of fertilisers and to provide governments with the advice and information necessary for developing national fertiliser programmes. It would achieve this through a field programme of fertiliser tests and demonstrations and through developing soil-testing laboratories and services. This collective approach by a large branch of the chemical industry to the problem of world nutrition is most encouraging and the F.A.O. is to be congratulated on the venture.

Natural rubber in roads

THE 1959 annual report of the Natural Rubber Development Board, which was published recently, mentions the further increase in world demand for natural rubber. Thus just over 2 million tons were consumed in 1959, compared with 1,957,000 tons in 1958. Much attention is now being focused on the use of rubberised road surfaces. Rubber seems to have much to offer different types of highway—possibly its most significant contribution is in the low overall cost of the road. There are few countries in the world at present without road sections of rubberised surface, but, although rubber has been used in every variety of bituminous surface, by far the greatest mileage has been in the form of surface dressings.

During the last year 86 known installations, representing 117 miles of highway incorporating rubber, were recorded. Many of these installations represent repeat layings, notably in Australia, where engineers through much experience are now firm adherents of rubberised bitumen. Good progress has also been made in the use of latex as an additive, particularly in South Africa, where it has been used extensively in slurry sealing. Latex/bituminous emulsions are at present in commercial production in South and East Africa, Australia, New Zealand and Singapore. Total sales cannot be ascertained, since much of the work is done through normal commercial channels, but those reported amount to 270,000 gal. for the year, equivalent to about 90 miles of road at normal rates of application. One example cited concerns a badly cracked concrete road, for which rubberised bitumen was prescribed in 1957 at a cost of £2,500/mile, as compared with estimates for non-rubberised treatment of £11,000/mile.

Plutonium for marine propulsion

THE British Ship Research Association's atomic team has for the past year been carrying out an investigation into the possible uses of civil plutonium as a marine fuel. Some preliminary ideas on this subject were put forward by J. E. Richards in a paper recently delivered to the Institute of Fuel. By referring to the nuclear power station programme in this country it can be seen that the natural uranium graphite-moderated reactors are expected to achieve a fuel utilisation of $\frac{1}{2}\%$ by the time the fuel elements are removed; this might perhaps be extended to 2 to 3% by recycling the plutonium recovered from the spent fuel. It may therefore be simpler to regard these reactors as consumers of natural uranium and producers of civil plutonium; and then to consider the most economic use that can be made of the secondary fuel.

The major difficulty in considering plutonium as a reactor fuel is that the nuclear properties are more complicated than those of U^{235} and have not been established accurately. Furthermore, little plutonium has in the past been available for experimental studies. Therefore, present-day estimates of the economics of feeding plutonium into slightly enriched uranium

reactors are unlikely to be very accurate and operating experience is required to substantiate such estimates. According to Dr. Richards it still seemed worth while making a more detailed study of the plutonium-graphite system specifically for marine propulsion, because this is a simple system and, provided that the present estimate of the price of civil plutonium is realistic, this fuel cycle should have economic promise. In addition, it would have advantages over the present concept of high-temperature gas-cooled reactors in that an appreciable amount of structural material could be tolerated in the core—in particular, stainless-steel fuel elements, and eventually ceramic materials such as silicon carbide, which could retain fission products at very high temperatures.

The general conclusion drawn by Dr. Richards was that there is, at present, no clear line of development towards an economic reactor in merchant ships. There is a very slender basis for selecting a reactor type and probably for reducing capital costs, but the question of whether fuel cost could be reduced sufficiently with slightly enriched uranium reactors would be decided only after some experience in the operation of enriched uranium reactors on land.

Niobium by fluidisation

A NEW process for the production of niobium (columbium)—a metal that may be increasingly important in future metallic nuclear reactor fuel elements—was described by Dr. J. H. Oxley, of the Battelle Memorial Institute, at the First International Congress of Chemical Engineering, jointly sponsored by the American Institute of Chemical Engineers and its Mexican counterpart.

In this process, hydrogen is used to reduce niobium pentachloride. The volatile niobium pentachloride is fed into a reactor chamber containing a fluidised bed of seed niobium. Subsequent reduction by the hydrogen fluidising gas at 1,500°F. produces metallic niobium which is deposited on the seed particles. Seed for the fluidised bed is replenished by grinding a portion of the end product and recycling it into the reactor. Present-day chemical and electrolytic processes for producing niobium are carried out on a batch basis. While the fluidised-bed vapour-deposition process has not been used previously in producing niobium, the fluidised bed technique has been applied commercially in the petroleum, mineral, and chemical industries. It is known, for example, that many metals can be deposited in a fluidised bed of seed particles, and, from both a chemical and a metallurgical viewpoint, the hydrogen reduction of niobium pentachloride appears to be particularly adaptable to a fluidised-bed reduction process.

The quality of niobium produced by the fluidised-bed process is at least as good as the premium quality niobium presently on the market, according to Dr. Oxley. The new process is capable of producing niobium with less than 500 p.p.m. impurities—well within the requirements for niobium used in nuclear reactor fuel elements.

Applications of geothermal steam

ONE of nature's most fascinating sources of energy is in geothermal steam springs which are found in the Northern Island of New Zealand. The Government of New Zealand has been interested in the industrial utilisation of these springs and to this end has already completed a 40- to 60-MW. power station at Wairakei. Although the electricity generated in this station only represents a small fraction of New Zealand's total requirements, further development is carried out constantly and it is soon hoped to increase the number of applications.

It is, therefore, of interest that a large pulp and paper factory situated in this volcanic region recently installed geothermal steam for its own use. This steam, extracted from wells drilled by the company itself, is expected to replace about 200,000 tons coal per year. The raw geothermal steam was at first used to supply wood-drying kilns at the sawmill in order to drive machinery in the wood-preparations plant and for paper drying in the tissue mill. However, due to impurities in the steam, this was unsuccessful. A steam generator is at present being installed to supply 45,000 lb./hr. of clean saturated steam at 50 p.s.i., which is about half the pressure of the raw steam. The company has found it more profitable to use geothermal steam in processing rather than in power generation. A heat exchanger is also to be built, and this should save the company another £100,000, since it will provide feed water suitable for high-pressure boilers. A second heat exchanger should provide another 50,000 lb. of clean steam at 150 p.s.i.

The Greeks had a word for it!

THE profusion of symposia is absolutely bewildering. We sometimes feel that they are self-propagating at an exponential rate of increase. Symposium, nowadays, can be used to describe anything from a learned society conversazione (which, incidentally, does not mean gossip with an Italian) to a tradesmen's get-together. It occurred to us, therefore, to look up the word ' symposium '. The result of our encyclopaedic endeavours was frankly hair-raising. Hitherto we had assumed in all naivety, that a symposium was simply a meeting or gathering arranged for the collection and exchange of opinions on various aspects of a subject. However, from the Oxford Dictionary we learned that a symposium was ' an ancient Greek after-dinner drinking party with music, dancers or conversation '. We decided to probe further into the matter, but Nuttall's Standard Dictionary gave an even worse account of a ' sim-*po*-ze-um ', describing it as ' a drinking together '; ' a merry feast; and a banquet with philosophic discussion '.

We have frequently reported that ' the symposium was well attended ' and some of our readers may have wondered why it deserved such a glorious fate. We trust that they now know the whole story and will eagerly survey our forthcoming events in order to book up at the next symposium post-haste.

Determination of Vapour-liquid Equilibria of Binary Mixtures

By P. M. Heertjes*

Determination of vapour-liquid equilibria is one of the most complicated physico-chemical operations confronting those engaged in the study of fractional distillation. In this article, Prof. Heertjes describes an apparatus recently developed in his laboratories to measure these equilibria rapidly and accurately.

AN apparatus for the determination of vapour-liquid equilibria of binary mixtures has been developed in the present laboratory on a concept of J. P. van Es.† Because this apparatus gives satisfactory results and also is fairly easy to operate, a presentation to a larger audience seemed worthwhile.

The principle on which the apparatus works is that from a liquid mixture a saturated vapour is generated. This vapour is dephlegmated by cooling; the liquid and vapour formed are kept in contact under adiabatic and isobaric conditions long enough to establish equilibrium. The equilibrium temperature is measured; vapour and liquid are then separated and analysed. By changing the composition of the original liquid mixture the whole temperature-composition diagram at constant pressure can be established.

Apparatus

The apparatus, drawn to scale, is shown in Fig. 1. The liquid mixture is contained in the round-bottom flask *a* of 1-l. capacity. Vapour is generated by means of electrical heating and passes *via* tube *b* to the equilibrium tube *c*. Tube *b* is insulated with asbestos cord to prevent excessive condensation.

The tube *c* consists of two parts. The small upper part *d* is not insulated and is empty. By heat loss to the atmosphere partial condensation occurs here. The mixture of vapour and liquid formed flows downwards in the actual equilibrium tube, which is filled with Raschig rings of glass. This part is, moreover, heavily insulated with a vacuum mantle of which the inside is covered with a layer of silver. An Anschütz thermometer *e* at the underside of tube *c* permits reading of the temperature of vapour and liquid in equilibrium.

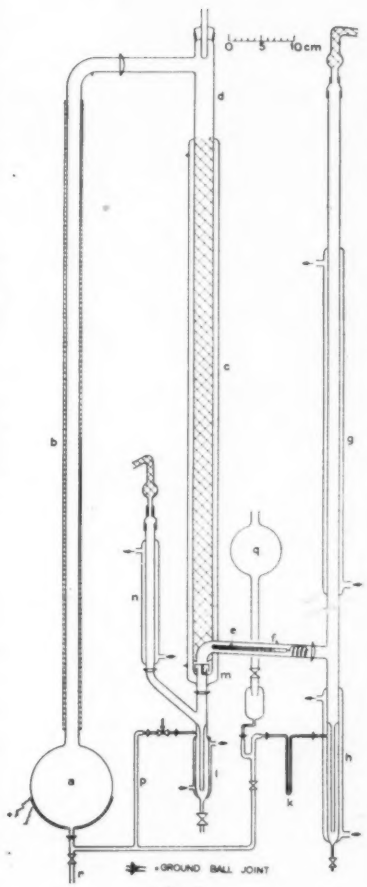

Fig. 1.

The vapour flows through tube *f* to the condenser *g*, cooled with water. The condensed vapour is returned to *a via* the cooled sample-receiver *h* and the U-formed liquid seal *k*.

The liquid from the equilibrium tube also is returned to *a via* the cooled sample-receiver *l* and the liquid seal *m*. For the proper functioning of this liquid seal, it is necessary that the pressure difference over the seal should be very small. Therefore the side tube *n* with condenser has been mounted.

All connections to the atmosphere have been provided with tubes filled with a desiccant (anhydrous calcium chloride in most cases) to prevent entrance of water vapour to the apparatus.

The sample-receivers are provided with inlet tubes which almost reach to the bottom. These must be completely filled before an experiment is started. The receiver *l* is filled through *p* from *a*. The receiver *k* is filled from the funnel *q* which is also used to add known quantities of the light or heavy component to the system to change the overall composition. The level of the liquid in flask *a* has to be kept constant. After each addition through *q*, to change the overall composition, the liquid level in *a* is readjusted by means of liquid withdrawal through tube *r*.

Operation

The liquid in container *a* is kept at a level ~2 cm. above the heating mantle. In operation, heating is regulated in such a way that the vapour from the equilibrium tube just reaches the underside of the condenser *g*. Before starting a measurement, the sample receivers have to be filled with liquid.

It is assumed that stationary conditions are reached if thermometer *e* (read in 0.01°C.) records a constant temperature. Generally this takes about 30 min. after the apparatus has been set in motion. As soon as

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stationary conditions are reached, 2 ml. of liquid are drawn from the sample receivers and discarded; a sample of 10 ml. is collected immediately in a stoppered Erlenmeyer flask and cooled in ice water. The samples are analysed.

A series of experiments is started with the pure light component to measure its boiling point. The heavy component is added *via q* to the system in as many steps as necessary to obtain a satisfactory representation of the equilibrium diagram—until a concentration of about 50 mol.%. Unless azeotropes are present, five steps are normally sufficient.

The apparatus is then emptied, thoroughly cleaned and dried and the procedure repeated, starting from the heavy component and adding the light component, again up to a concentration of about 50 mol.%.

The boiling points obtained are corrected for the difference in pressure from one atmosphere from the $\frac{dT}{dP}$ values of the pure components. For mixtures generally a linear intrapolation can be used, because near one atmosphere the $\frac{dT}{dP}$ values do not differ very much (~0.05°C./mm. Hg).

For the analysis of the samples the refractive index can often be used as can the boiling point as determined with the micro-apparatus of Cottrell. In both cases, calibration curves with synthetic mixtures have to be prepared.

To give the reader an idea of the possibilities of the apparatus, one example will be presented here, the vapour-liquid equilibrium for benzene-toluene at one atmosphere pressure. This system has been chosen because, despite the fact that many equilibrium diagrams are to be found in the literature, as far as the authors have found, no determined values have been published. All diagrams published have been calculated under the assumption that both phases are ideal, *i.e.* that the liquid phase follows Raoult's law and the gas phase follows Dalton's law. The justification for this has to be found in the work of Beatty and Calingaert,[1] who have shown that, at 80°C., the determined vapour pressure, and the calculated vapour pressure using Raoult's law, differed less than 0.5% at the maximum.

In Table 1 the data for one atmosphere as found with the apparatus by J. de Graauw have been collected.

Table 1

Temperature	*Liquid*			*Vapour*			
°C.	x	x^*	$x^* - x$	y	y^*	$y^* - y$	$\frac{y^* - x^*}{y - x}$
80.10	100.0	100.0		100.0	100.0		
81.18	94.1	94.6	0.5	97.3	97.8	0.5	1.00
81.92	90.4	90.9	0.5	96.0	96.2	0.2	0.95
81.99	90.0	90.5	0.5	95.8	96.0	0.2	0.95
84.10	81.0	81.1	0.1	91.1	91.9	0.8	1.07
86.41	71.2	71.5	0.3	85.3	86.5	1.2	1.07
88.63	62.8	62.8	0.0	80.0	81.0	1.0	1.06
90.76	55.1	54.9	−0.2	74.2	75.2	1.0	1.07
92.76	48.3	47.8	−0.5	68.8	69.4	0.8	1.05
95.01	40.7	40.5	−0.2	61.9	62.6	0.7	1.04
97.76	32.5	32.0	−0.5	53.0	53.6	0.6	1.05
101.52	21.9	21.6	−0.3	39.5	40.0	0.5	1.05
103.00	18.3	17.8	−0.5	33.4	34.2	0.8	1.08
104.87	13.2	13.1	−0.1	25.7	26.6	0.9	1.08
103.42	4.7	4.8	+0.1	10.4	10.4	0.0	0.98
103.75	4.2	4.1	−0.1	8.9	8.8	−0.1	1.02
110.62	0.0	0.0					
		Mean = −0.03			Mean = +0.61		= 1.03

The composition of the vapour (y) and of the liquid (x) in equilibrium have been expressed in mol.%. Moreover, the calculated values of the liquid composition (x^*) using Raoult's law for each temperature and of the vapour composition (y^*) from this liquid composition, using Dalton's law, have been included.

The vapour pressures of the pure components at different temperatures have been selected from literature values. For benzene the values of Smith,[2] Zmaczynski[3] and Smith and Menzies[4]; for toluene, the values of Rossini[5] and Zmaczynski[3] have been used. Benzene and toluene had been carefully purified and dried before use.

From the data it can be seen that the most likely conclusion is that equilibrium is approached sufficiently and that the liquid mixtures of benzene and toluene follow Raoults' law rather closely. The difference in liquid composition as found are ± 0.5 mol.% at the maximum.

Moreover, it can be concluded that the vapour does not behave as an ideal gas, although the differences are not very large.

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Veale Committee Report

A report on the training of radiological health and safety specialists was published recently. This committee, under the chairmanship of Sir Douglas Veale, was set up to consider the national need for specialists to deal with the health and safety aspects of the use of ionising radiations and radioactive substances. The increasing use of radiations for peaceful purposes has created a shortage of these specialists, and the report makes recommendations about the types of experts needed and their training. It is at present being studied by the U.K.A.E.A. and the government departments concerned.

Methods of training for radiological health and safety staff at three levels are considered. At the top level, university postgraduate courses have already been set up to give a wide training—overlapping the boundaries of medicine, biology, physics and chemistry—to selected graduates in science or medicine. There are courses in the universities of London and Birmingham, and Edinburgh University is planning a course to start next October. The committee believe that these courses, when fully developed, will be sufficient to meet the need for 20 or 30 top-grade specialists a year.

The report recommends that similar courses of a rather less advanced kind should be set up at two or three colleges of advanced technology. At a somewhat lower level again, a scheme is suggested for introducing certificate courses at technical colleges in the autumn of 1961.

Wood Distillation

Still a source of chemicals in the oil age

By M. Schofield
M.A., B.Sc., F.R.I.C.

Fig. 1. Pyroligneous acid storage vats at Worksop.

The art of wood distillation is one of the oldest branches of the chemical industry in Great Britain. In this era of petrochemicals one is liable to forget that many important hydrocarbons were previously obtained from wood. The author, who has been associated with the British wood distillation industry for many years, gives an authoritative survey of this industry and reviews its position in the 1960*s.*

THE destructive distillation of hardwoods with the recovery of volatile products has within recent years taken on a new lease of life by use of vertical continuous retorts heated by inert gases. When synthetic methanol came almost to supersede wood spirit, when both synthetic and fermentation acetone became fully established together with modern acetic acid production, it seemed certain that the old wood distillation industry was doomed since it could not depend solely on charcoal, now produced in portable kilns in place of ancient meilers. Yet even in Britain, with our limited hardwood resources, the industry went on, first with slung horizontal ovens or ' Jumbos ' holding ten cords of wood in four buggies or retort cars, and then with the new Lambiotte vertical retort process established at Worksop within the last three years.

After years of failure with horizontal retorts carbonising small waste or even sawdust, with retort walls burning through despite the use of ' floating ' or loose chippers for removing insulating charcoal causing this failure, it is absorbing to follow this development or change to inert-gas heating in vertical retorts of high efficiency. The industry attracts further interest in that azeotropic processes like that of Othmer have been incorporated in British wood distillation as elsewhere for recovery of a higher grade of acetic acid than that recovered from grey acetate of lime.

Early development

The industry arose in this country when John Aldred began to make retort charcoal for the Sheffield iron industry and then turned to acetic acid recovery by adding scrap iron to the pyroligneous acid. He moved his works and eventually arrived at Worksop on the borders of Sherwood Forest at the beginning of this century. Other works became established at places near to the raw material, namely forest waste in the form of billets, slabs and branches left after timber had been selected. Thus there was at one period a small works near the Wrekin Forest in Shropshire, a second Aldred factory at Warminster, while yet another example, still thriving today and working Jumbo ovens, is at Speech House Road in the Forest of Dean.

The slung Jumbo oven replaced smaller rectangular and cylindrical retorts influenced in design by early gas retorts, an influence reminding one of other links between the two carbonising industries. Thus coal-tar creosotes more than rivalled wood creosote except for special cases as when guaiacol is produced from wood-tar; while, on the other hand, the coming of coal-tar colours like magenta and ' Night Green ' brought demands for wood-spirit. Wood-gas with 3% hydrogen, 33% carbon monoxide, 3.5% methane, and the rest carbon dioxide and water vapour, has never been of significance, being burned under the boilers or retorts in the older processes other than in vertical retorts.

Before the horizontally-slung oven taking four retort cars of steel lattice bodies became the standard pattern in Britain and in the large American plants with up to 20 ovens, there were many examples of cylindrical types, even vertical types in France, together

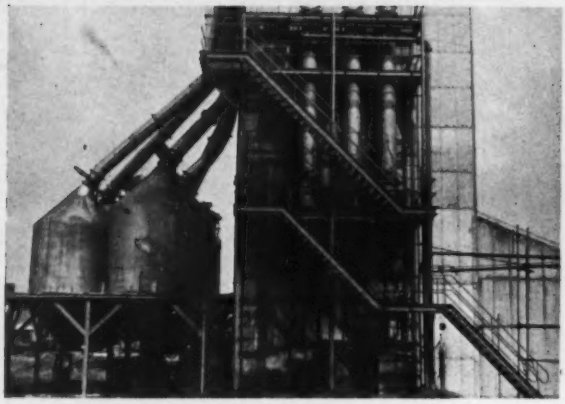

Fig. 2. Vertical coolers and charcoal conditioning bins at Worksop.

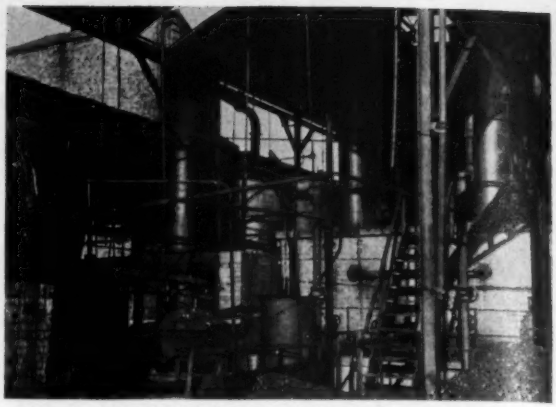

Fig. 3. Wood distillation unit in the Forest of Dean.

with Schwarz kilns like giant muffle furnaces and Reichenbach ovens of 400-cu.m. capacity in European plants. The closer comparison between British and American retorts was to be expected since Turnbull of Glasgow as early as 1849 built and operated the 'Scotch' works at Milburn, N.Y., where 9-ft. iron cylinders in pairs constituted carbonising units. Seventy years ago came the Jumbo ovens, superior in dealing with large bulky materials and in charging and discharging *via* oven doors, yet still inefficient as regards heat losses through retort walls and spaces. Spiral and worm condensers gave way to tubular types, while later still, Kestner evaporators and column stills added to improved working of wood distillation plants.

Horizontal ovens as standard

Since the ten-cord oven retort became the normal pattern for carbonising forest waste up to 4 ft. in length of branches and billets, its operation may now be summarised before turning to inert gas heating and other innovations. While at Worksop the introduction of the Lambiotte process brought suspension in use of the four ovens; at the Forest of Dean works five such ovens made by Blairs of Glasgow are in use. This works developed when Thomas Newcomen took over an old wood distillation plant and formed the Lydbrook Chemical Co., now Wood Distillation Ltd. Like other British plants it had an intensive working period during the first world war when the urgent call for acetone brought a revival in a number of carbonising units since becoming obsolete. The forest waste, seasoned or air-dried for some months, is charged into the steel-lattice buggies or cars, four cars charging ten cords of material being run into each oven; a cord of wood is about 3,000 lb. and yields 1,000 lb. charcoal. The retort doors are closed, outer storm doors swung to, and the 24-hr. distillation period begins. This period is in four stages: water vapour and a little gas coming from the first; then darker distillate of pyroligneous acid accompanied by gases; then the exothermic decomposition sets in during which firing has to be greatly reduced; and finally the hot firing period to remove less volatile components and avoid partially-carbonised or 'foxey' charcoal.

From 20 tons of wood waste come 2,650 gal. pyroligneous acid, 6 to 6½ tons of charcoal and 5 tons of wood-gas. In contrast, American and Canadian oven processes pre-dry the wood charge which requires much less space, by use of waste heat, the advantage of this appearing in the more concentrated pyroligneous acid. A typical plant was built by the Kodak subsidiary, the Tennessee Eastman Corporation utilising wastes from producing box cameras, spools, packing cases and other photographic requirements. Twelve ovens of the 'through type' have retort doors opening at both ends for more rapid discharge of charcoal into the 'coolers' (sheet-iron tunnels for sealing off the charcoal from air). In place of the winch for hauling cars from the retort mouth, a 'transfer' using electric power moves the cars to the rail-ends leading to the charcoal coolers. From the coolers the charcoal passes to the grinding and grading section where, apart from lump charcoal, eight grades of granular sizes from pea size to powder are produced together with briquettes for dining cars and barbecues. The main products of importance are solvents for the photographic film industry to be referred to later.

Other carbonising units

Among alternatives to slung horizontal ovens or Jumbos are continuous mechanical retorts and vertical retorts, the latter proving most efficient, particularly when combined with the use of inert gases or wood-gases within the retort itself. Small wood waste, such as bobbin chippings produced in Lancashire and at Paisley, and sawmill wastes and even sawdust, was carbonised with varying degrees of success during the early part of this century.

At Swinton the problem of removing insulating layers of charcoal causing burning-through of retort walls was solved by use of loose breakers or chippers rotating and falling as the retort revolved. Yet the problem of carbonising several million tons of sawdust remains unsolved, a state of affairs hinted at when a prominent Kassel firm squandered £4 million in efforts to produce charcoal briquettes from sawdust.[1] Yet sawmill waste hogged to convenient size is the raw material of modern wood distillation except for the horizontal oven processes still surviving. A first successful move towards using such waste came in the 1920s when the Ford Co. at Dearborn, Michigan, put into operation vertical retorts operating the Badger-Stafford process.[2] While sawdust and shavings were treated in rotary retorts, the success of which is not known, larger wood waste from the shops was reduced to 8-in. pieces, tramp iron removed, moisture brought down to 0.5% by pre-drying, and the waste distilled in retorts requiring no external heating. Once the initial

temperature has been reached within a freshly charged retort by burning wood-gas, an exothermic decomposition sets in and enables a two-week operation period of continuous distillation before each retort is disconnected for burning-out of accumulated tar or pitch. Air-tight barrel valves at the top and bottom of the retorts enable the charging of wood and discharging of charcoal, the incoming wood being heated by the exothermic reaction near the middle of the retort where the temperature is 515°C. The 40-ft.-long retorts are vertical cylinders insulated within by a firebrick lining.

A further improvement is in cooling and conditioning the charcoal, the rotary coolers being 30-ft. long and lined with water tubes apart from water-cooling on the exterior surface, conditioning taking only five hours in place of the two days' conditioning required in the tunnel coolers used in the oven process. The pyroligneous acid, like that in all plants using predried wood waste, is more concentrated than the older type of distillate from seasoned wood. It is distilled to remove dissolved tar (a useless distillate burned beneath the boilers) and then goes to continuous stills to yield 95% purity of wood spirit and a 15% acetic acid. The methyl alcohol is refined to a high-grade methanol, with invaluable solvent by-products such as methyl acetate and *methyl acetone* (a trade name for a methanol-methyl acetate-acetone mixture). In place of recovering acetic acid either *via* calcium acetate or by solvent extraction, esters are prepared by some American distillers without concentrating the acetic acid, an example being the Badger-Stafford plant producing ethyl acetate.

Continuous retorts with inert-gas heating

With the challenge of synthetic methanol and acetic acid, with acetone coming from the Weizmann fermentation process and from isopropyl alcohol from the petroleum chemical industries, and with improved portable kilns producing charcoal from forest waste, the wood distillation industry has been driven to seek more efficient plant using wood waste hogged and distilled in automatically-charged retorts heated by inert gases. By use of continuous vertical retorts allied with extraction processes for producing concentrated acetic acid, and by a flexible production of various solvents to meet market requirements, a new phase has entered the old industry. For some years the older retort processes had been condemned because of heat losses through retort walls and through gaps within the forest waste stacked haphazardly in the retort cars.

It had been well appreciated that greater efficiency would be attained by use of hot oxygen-free inert gases circulating within the loosely-packed wood waste, an appreciation which brought practical results in Europe in the 1940s. Thus in 1942 two wood distillation plants in Switzerland began such a use of vertical retorts and of inert gases surrounding individual pieces of wood and bringing them to the point of exothermic decomposition. At the Iron Mountain plant of the Ford concern and in subsequent vertical retorts, hogged wood is fed *via* airtight valves into the retorts, a current of pyroligneous acid vapours moving downwards in the retort while the inert gases rise through the wood waste. In this process, in which the retort has different zones of reactions, the rising gas also dries the wood charge before leaving the top of the retort at 212°F. From the base of the retort the charcoal is continuously discharged into conditioners *via* a valve.

This Swiss process has also been operated in a pilot plant at the Brooklyn Polytechnic on behalf of the North-Eastern Wood Utilization Council of New Haven, the results being reviewed by R. S. Aries.[3] Gas heated with part of the de-tarred wood-gas is blown into the retort, extra 'rinsing gas' being generated if required from charcoal or other fuels. Advantages claimed are: continuity with heat economy, a charcoal output of more than double that of normal retorts as regards unit volume, no power required for discharging, and no large charcoal coolers required. Above all, as is found in all such continuous vertical retorts using inert gas, the whole distillation process is under control with a regulated charring rate.

This *Ticino* process in Switzerland was part of a general development in European countries of inert-gas processes, with Germany, France and Belgium operating such continuous retorts before a modified process was begun at Worksop. In Germany during the war the *Reichert* process was dominant, as the F.I.A.T. Final Report No. 444 of 1945 described. Reichert covered his method in two U.S. Patents[4] and used a vertical retort with conical ends. After removing condensable vapours in condensers and scrubbers, part of the wood-gas is used to heat the remaining gas to 500 to 600°C. This hot gas is now driven from top to bottom of the retort to pass through the wood waste, the rate of passing being maintained high enough to avoid condensation of tar or volatiles brought by the gas from the base of the retort. The exothermic reaction developed in the distillation zone is fully utilised and under control in such a zoned retort.

Although a number of *Reichert* plants had proved successful in Germany, together with one in the U.S., even more attractive to wood distillers was the process of A. Lambiotte, which was patented in 1939 in France[5] and further covered in America in 1942.[6] This process, now used in modified form at Worksop, is completely continuous, in contrast to the *Reichert* method used as a batch process, and claims to produce yields of acetone and methanol of up to 30% higher than with older forms of retorts, apart from greater flexibility and suitability for operating con-

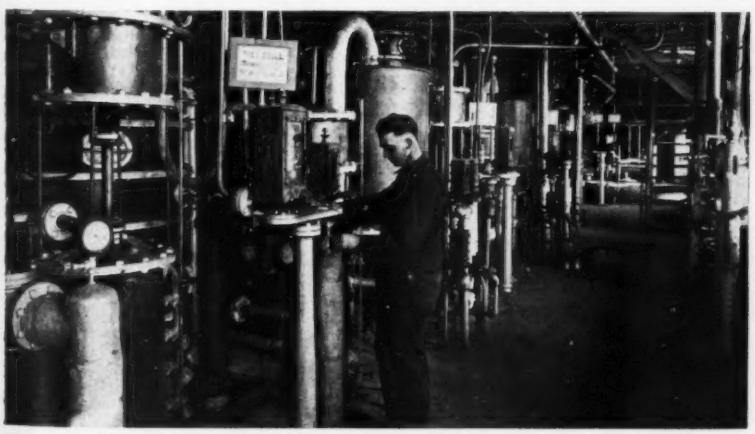

Fig. 4. A refinery for wood products and solvents for manufacturing photographic film at the Eastman Kodak Co.

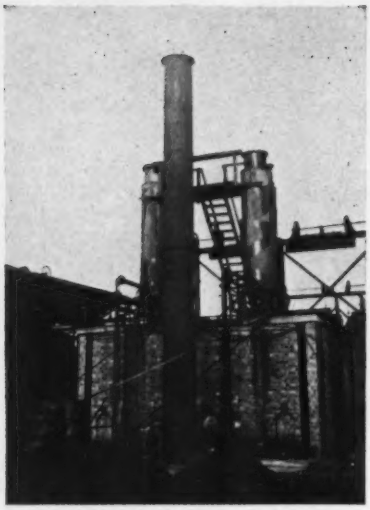

Fig. 5. Back of oven retort in the Forest of Dean works.

ditions in Britain. Here again a zoned retort is operated, the hot inert gases being introduced halfway down the retort and not at the top as with Reichert's process. The downward progress of wood waste and upward flow of gases are controlled so that the final drying of the wood is ensured in the upper zone. (This is practical, since for the first time in this country pre-drying of the hogged wood, reducing moisture content from 45 to 15% by use of boiler flue-gases, is used.) The moisture-free charge enters the distillation zone, while the exothermic reaction begun opposite the inert gas inlet continues through a third zone. Since charcoal is now cooled in conditioning bins by the side of the retort house, more efficient cooling is ensured by use in the lowest zone of the retort of a small flow of cool gas.

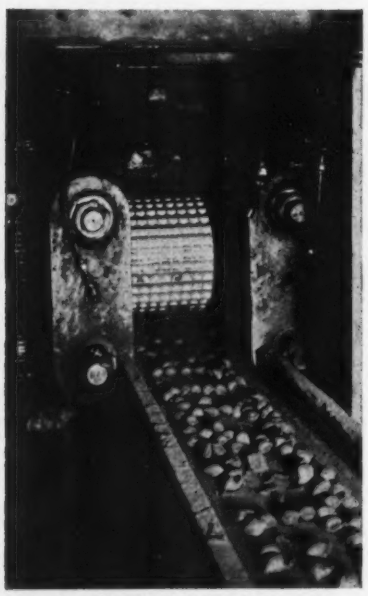

Fig. 6. Charcoal briquette making.

In actual operation, hardwood waste cut to 1-ft. pieces passes in 3-ton bogies through the pre-driers, thence over a weighbridge to a tippler tilted to 50° in dropping the charge on to the wood conveyor automatically filling the skips of a hoist. Thence the wood is charged into the top of the retort, a control of the dip-stick type measuring the level in the retort and thus actuating the addition of fresh charges automatically. From the base, charcoal is removed *via* a valve, dropped to a conveyor belt, and after screening to remove fines it goes to the large conditioning bins where oxygen adsorption is controlled before the charcoal is graded. Volatiles and wood-gas leave the retort near the top, a spray of cold pyroligneous acid removing most of the tar with the remaining vapours and gas passing to the main condensers. Any excess gas not used in the retort process is used in the pre-drying of the wood as an addition to any use of flue-gases for this. Any required temperature of gas entering the retort, usually between 450 and 560°C., is obtained by use of a gas furnace external to the retort.

Distillation products

After removal of settled tar and then further removal of dissolved tar by distillation, the wood distiller has available two rival processes for producing concentrated acetic acid, these being alternatives to the older liming method to yield grey acetate of lime reaching 80 to 82% quality. (Grey acetate and even some iron liquor for the textile trade are still produced to meet some market demands, however.) The first of such extraction processes is the *Suida* process,[7] at one time widely adopted in the U.S. and by European wood distillers. The advantage is in using a high-boiling wood-oil fraction obtained from a tar which has never become of prime importance in commerce, thus avoiding the buying of solvents for extraction. Vapours of acetic acid, methanol and water from a primary boiler rise in a scrubbing column in counter-current to solvent oil which dissolves the acetic acid. The resulting solution goes down a dehydrating column to a secondary boiler which delivers the hot liquor to a stripping column working under vacuum; thence acetic acid vapour passes to enter a rectifying column to yield 92% acetic or even higher concentrations. The *Suida* process proved by no means cheap to operate, with so much water vapour handled by scrubbing columns and with heavy construction needed for the vacuum part. Hence a second extraction method has appeared in the U.S. and at Worksop, the *Othmer* process[8] using a 'withdrawing agent', butyl acetate (with other alternative solvents specified). Butyl acetate distils with the water as a minimum-boiling azeotrope, thus removing water from the acetic acid. After standing to separate, the butyl acetate is returned to the top plate of the column while any butyl acetate in the water is recovered. The acetic acid containing 0.5% water plus a little tar and propionic acid is rectified in a still. The wood spirit fraction is charged daily to a small still with column, three fractions collected being the ternary azeotrope 'methyl acetone' (21% methanol, 28% methyl acetate and 51% acetone), then a second fraction of methanol still with the other two solvents, and a third used as denaturing spirit.

A final reference to applications of products serves as answer to those who imagine wood distillation to be dead. First to be mentioned is charcoal, a product consumed in Britain at the rate of 20,000 tons, with part coming from imports and from portable kilns used in the wake of the timber producer. A main demand is for carbon disulphide manufacture, with smaller outlets in case-hardening compositions, in non-ferrous metallurgy, in combustion stoves, grills and the new motif for barbecues. A special crack-free charcoal in block form is produced for use in polishing lithograph rolls for etched pictures. Various solvents and denaturing liquids are produced by the wood distiller for the paint, paint-stripping and lacquer markets, while from European wood-tar has come guaiacol and other special fractions. As example of the versatility of the wood distiller in Britain may be mentioned the use of his plant in off-periods for reclaiming customers' solvents after cleaning, at a cost much below that of fresh solvents.

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Sigma Phase in Austenitic Stainless Steels

By R. F. Hills, * A.I.M., and D. R. Harries, * B.Sc., Ph.D.

Austenitic stainless steels are potential fuel element canning materials for nuclear reactors operating at high temperatures. One of the principal requirements of the canning material is that it should have sufficient ductility under the operating conditions to prevent failure. Annealed, austenitic steels meet this requirement satisfactorily but the ample ductility may be reduced by the formation of an embrittling phase, termed sigma, during long periods of heating below the annealing temperature. This article surveys the information available on the formation of sigma and its effects on the properties of austenitic steels.

BECAUSE of their high resistance to oxidation and corrosion, austenitic steels have been used in the chemical industry for about 35 years. The original austenitic steels contained only chromium and nickel as the alloying elements, the carbon contents being 0.1 to 0.2%. The actual chromium and nickel contents were varied, but eventually the 18%Cr—8%Ni and the 25%Cr—20%Ni types came into most general use. More recently the use of austenitic steels has been extended to gas turbine and jet propulsion engines and more highly alloyed steels possessing good corrosion and superior creep resistance at elevated temperatures have been developed. The standard types of American stainless and heat-resisting steels with chemical ranges and limits are given in Table 1.

In the condition in which the iron-chromium-nickel austenitic steels are normally supplied, namely, annealed by rapidly cooling from temperatures in the range 950° to 1,250°C., the structure of the steel consists of austenite. Heating the austenitic structure at temperatures between about 450° and 700°C. (known as the sensitising range) results in the precipitation of $M_{23}C_6$, the carbide based on $Cr_{23}C_6$, at the grain boundaries. The areas of austenite adjacent to these carbide particles are impoverished in chromium and the steel is susceptible to severe corrosion in the grain boundary regions. When it is necessary to heat in this temperature range the extra-low carbon grades 304L and 316L have definite advantages since they will not sensitise in the heating times involved in normal fabrication. However, even these low - carbon grades become sensitive to intergranular corrosion after extended heating periods in the 540° to 600°C. range.[1]

The susceptibility of these steels to intergranular attack after welding or heating at these temperatures is nullified by addition of elements such as titanium or niobium which have a greater affinity for carbon than chromium. These additional elements form stable carbides on heating the annealed steel at temperatures between about 700° and 900°C. (known as the stabilising range), the chromium remains in solid solution in the austenite and the corrosion resistance is maintained. However, the so-called 'stabilised' steels can never be fully stabilised.[2] Thus the presence of niobium or titanium, in amounts more than sufficient to combine with all the carbon, does not prevent precipitation of $M_{23}C_6$.

Titanium and niobium carbides exist as separate phases in the austenitic steels; the effect of adding titanium or niobium is therefore equivalent to reducing the carbon content of the steel matrix. Such a reduction in carbon content has the effect of increasing the instability of the austenite and a steel with sufficient titanium or niobium to prevent carbide precipitation is generally a duplex steel; it contains principally austenite with some δ-ferrite.

These two elements can therefore be referred to as ferrite formers when added to a chromium-nickel-base material. Additions of molybdenum to improve strength at elevated temperatures and to enhance the corrosion resistance in certain environments, and silicon to improve resistance to oxidation and carburisation have similar ferrite-forming tendencies.

Therefore, modern austenitic steels generally consist of three principal phases—austenite, ferrite and carbides—the relative proportions being determined by the composition and heat treatment. On subsequent reheating in the temperature range 550° to about 970°C. another phase may appear. This is a hard, brittle, non-magnetic phase which has been termed sigma (σ). Other intermetallic phases have also been identified in the last few years in austenitic alloys.[2–7] With the exception of the σ phase there is insufficient data for assessing their effects on the properties of the steels.

Formation of sigma phase

The existence of the sigma phase approximating to the composition of FeCr in iron-chromium alloys has been definitely established by a number of workers. The limits of existence of this phase have not been completely defined at ordinary temperatures owing to the slow rate of approach of these alloys to equilibrium. However, part of the iron-chromium diagram showing the phase boundaries of the sigma and alpha phases between 800° and 600°C. as determined by Cook and Jones[8] is shown in Fig. 1. The σ phase exists alone in the composition range 44 to 50 at % Cr, but

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Table I. Standard types of American stainless and heat-resisting steels with chemical ranges and limits

	Chemical composition, %														
Type No.	*C*	*Mn max.*	*P max.*	*S max.*	*Si max.*	*Cr*	*Ni*	*Mo*	*Zr*	*Se*	*Ti*	*Cb-Ta*	*Ta*	*Al*	*N*
301	0.15 max.	2.00	0.045	0.030	1.00	16.00 18.00	6.00 8.00								
302	0.15 max.	2.00	0.045	0.030	1.00	17.00 19.00	8.00 10.00								
302B	0.15 max.	2.00	0.045	0.030	2.00 3.00	17.00 19.00	8.00 10.00								
303	0.15 max.	2.00	0.20	0.15 min.	1.00	17.00 19.00	8.00 10.00	0.60	0.60						
303Se	0.15 max.	2.00	0.20	0.06	1.00	17.00 19.00	8.00 10.00			0.15 min.					
304	0.08 max.	2.00	0.045	0.030	1.00	18.00 20.00	8.00 12.00								
304L	0.03 max.	2.00	0.045	0.030	1.00	18.00 20.00	8.00 12.00								
305	0.12 max.	2.00	0.045	0.030	1.00	17.00 19.00	10.00 13.00								
308	0.08 max.	2.00	0.045	0.030	1.00	19.00 21.00	10.00 12.00								
309	0.20 max.	2.00	0.045	0.030	1.00	22.00 24.00	12.00 15.00								
309S	0.08 max.	2.00	0.045	0.030	1.00	22.00 24.00	12.00 15.00								
310	0.25 max.	2.00	0.045	0.030	1.50	24.00 26.00	19.00 22.00								
310S	0.08 max.	2.00	0.045	0.030	1.50	24.00 26.00	19.00 22.00								
314	0.25 max.	2.00	0.045	0.030	1.50 3.00	23.00 26.00	19.00 22.00								
316	0.08 max.	2.00	0.045	0.030	1.00	16.00 18.00	10.00 14.00	2.00 3.00							
316L	0.03 max.	2.00	0.045	0.030	1.00	16.00 18.00	10.00 14.00	2.00 3.00							
317	0.08 max.	2.00	0.045	0.030	1.00	18.00 20.00	11.00 15.00	3.00 4.00							
321	0.08 max.	2.00	0.045	0.030	1.00	17.00 19.00	9.00 12.00				5 × C min.				
347	0.08 max.	2.00	0.045	0.030	1.00	17.00 19.00	9.00 13.00					10 × C min.			
348	0.08 max.	2.00	0.045	0.030	1.00	17.00 19.00	9.00 13.00					10 × C min.	0.10 max.		

is unstable above 820°C. The σ phase can exist between the limits 26 and 71 at % Cr at 600°C.

There is now little doubt that the hard, non-magnetic phase first observed by Bain and Griffiths[9] in ternary iron-chromium-nickel alloys is the compound FeCr in which some of the iron or chromium atoms have been replaced by nickel. Although phase diagrams defining the limits of σ phase regions in iron-chromium-nickel alloys of high purity have been reported,[10] they are of little value in predicting the susceptibility to σ formation in commercial alloys having a composition that lies close to the phase boundary. In such alloys, variations in composition within the specified range and the presence of normal amounts of steel-making elements may be sufficient to induce the formation of σ, a condition which would not have been predicted from the phase diagrams for pure alloys. There are insufficient quantitative data available for accurately assessing the displacement of the phase boundaries due to the alloying elements other than chromium and nickel found in commercial austenitic steels. However, the effect of alloying elements on the compositional limits and sigma formation may be broadly summarised by saying that elements which can be designated as ferrite stabilisers (Cr, Si, Mo, Al, W, V, Ti and Nb) promote the formation of sigma.[11] Silicon has a pronounced effect on the formation of sigma by increasing the amount of the phase and its speed of formation.[12] The austenite stabilisers (C, N, Ni and, to a lesser extent, Mn) generally retard the formation of sigma.[11]

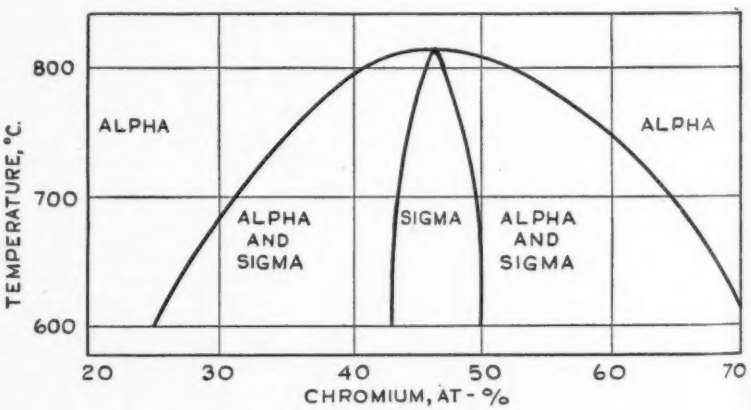


Fig. 1. Part of the Fe-Cr diagram.

With the possible exception of austenitic stainless-steel types 301, 302, 304 and 308, annealing followed by reheating of the other austenitic steels causes the progressive formation of the sigma phase from the metastable ferrite and austenite.[11, 12, 16, 20–22] It had been originally thought that the sigma phase formed only from the unstable ferrite rather than directly from the austenite. However, there is now ample evidence that the sigma forms in some austenitic steels that are free from ferrite at the annealing temperature. The relative rates of sigma formation may differ considerably, often being slower from austenite than ferrite, although this depends on steel composition.

Formation of metastable ferrite

The formation of sigma from ferrite and its effects have been extensively studied in 18%Cr—8%Ni[13–17] and 25%Cr—15%Ni[12, 20] type austenitic steels. In wrought samples of these steels the ferrite islands are drawn out into elongated groups in an austenite matrix. The amount of ferrite present is dependent on the composition and solution treatment temperature; up to about 40% ferrite may be present after annealing. The sigma phase is formed in the chromium-rich ferrite areas in an 18%Cr—8%Ni—3%Mo titanium-stabilised steel on heating for 1 hr. at temperatures in the range 600° to 950°C. The maximum rate of sigma formation occurs at about 850°C. At this temperature the formation of sigma is progressive, commencing at very short times, certainly less than 5 min., and being substantially complete after 2 hr. when the steel becomes apparently non-magnetic. The reduction in ferrite content due to sigma formation after reheating at the indicated temperature for 4 hr. followed by air cooling to room temperature is shown in Table 2 together with the hardness values, which are not markedly affected.

Table 2. Effect of sigma formation on the hardness of a duplex austenitic stainless steel

Reheating temperature, °C.	*Ferrite, %*	*Hardness, V.P.N.*
Nil	43	200
500	43	220
550	42	199
600	37	200
650	33	203
700	30	211
750	11	229
800	5	231
850	3	237
900	12	217
950	25	210
1,000	37	186
1,100	40	184

Optical microscope studies of the formation of sigma phase in duplex δ-ferrite and austenite steels have shown that the delta ferrite breaks down to an unresolvable product at the ferrite/austenite interface and that the reaction then grows inwards consuming the whole of the δ-ferrite grain. Electron microscope investigations of solution-treated 25%Cr—15%Ni steel specimens sigmatised at 700°C. and 900°C. have given a much clearer picture of the processes involved.[23]

Formation from austenite

Detailed investigations of the formation of sigma phase from austenite have been made in 25%Cr—20%Ni steels[11, 21] and 25%Cr—15%Ni steels with suitable adjustment of the carbon and silicon contents such that the steels were wholly austenitic when quenched from temperatures of 950° to 1,250°C.[12, 20]

Wrought 25%Cr—20%Ni steel bar normally heat treated by air cooling or water quenching from 1,050° to 1,150°C. is austenitic and entirely free from ferrite. Chromium carbides may be present in amounts depending on the carbon content of the steel and the annealing or solution treatment. Commercial 25%Cr—20%Ni steel is unstable below about 925° to 1,000°C., depending on the silicon content, the equilibrium phases being austenite, sigma and chromium carbide. Exposing a 25%Cr—20%Ni steel, rapidly cooled from 1,050°C. to produce an austenite grain size A.S.T.M. 7 to 8, for 200 hr. at temperatures in the range 650° to 950°C. results in the formation of grain boundary sigma.[11] The percentage sigma formed at the various annealing temperatures together with the hardness values are given in Table 3. The grain boundary sigma precipitates formed at 750°C. and above are massive but the effects on the hardness are relatively minor.

The analysis of a sigma residue extracted by anodic treatment of a 25%Cr—20%Ni steel in a solution of potassium iodide and citric acid is as follows:[11] 0.37% C; 2.67% Si; 0.63% Mn; 9.39% Ni; 45.94% Cr; 39.48% Fe.

The distribution of σ formed at 800°C. in a 25%Cr—20%Ni steel is considerably influenced by the prior heat treatment but only in so far as this affects the grain size.[11] Reheating fine-grained steels (A.S.T.M. 7 to 8) originally softened at 1,050°C. produces a granular or equiaxed precipitation of σ at the grain boundaries, often at the intersection of three grains. Up to 18% σ can be precipitated in this way. Softening at 1,150°C. to produce a grain size A.S.T.M. 2 to 4 dissolves all the carbides and coarsens the grain size. The σ formed during subsequent reheating at 800°C. appears first at the grain boundaries and later as continuous laths or sheets marking certain crystallographic planes within the grains. The carbides are also reprecipitated during treatment at 800°C. These coarse-grained steels carry only a proportion of their σ precipitates at the grain boundaries (about 5% by volume of the steel). Amounts of σ in excess of 5% are formed at 800°C. as Widmanstatten precipitates inside the grains. The grain boundary σ in coarse-grained steels is plate-like rather than granular and is more effective in separating the grains.

In some steels of this type high-temperature softening retards the rate of σ formation and also increases the time before σ can be detected: 500 hr. at 800°C. were required to produce the first appearance of σ in coarse-grained specimens from a steel of composition: 0.12% C; 1.46% Si; 0.79% Mn; 21.0% Ni; 24.23% Cr (softened at 1,150°C.), whilst a similar treatment on the corresponding fine-grained specimens produced almost the equilibrium σ content.[11] No sigma was detected in the 1,150°C. annealed specimens during the first 72 hr. of heating at 800°C., but marked carbide precipitation occurred. Conversely, little carbide was precipitated at 800°C. as in the 1,050°C. annealed specimens, but σ was first detected after only 24 hr. at 800°C. The tendency for chromium carbide to precipitate before the σ might be explained in terms of the relative rates of diffusion of C and Cr in austenite at 800°C., the greater mobility of carbon atoms being such as to involve much of the initial diffusion of Cr in precipitation of chromium carbide. When the free carbon is exhausted, or nearly so, further diffusion of chromium in the still unstable austenite will precipitate σ.

Sigma forms more rapidly and over a wider temperature range (540° to 870°C.) in cold-worked 25%Cr—20% Ni steel than in annealed material (595° to 870°C.)[11,21,24] However, this effect is small in fine-grained steels unless heavy deformations (about 40% elongation) are applied; cold work is much more effective in promoting formation in coarse-grained austenitic steels.

It was originally suggested[11] that cold work accelerates the formation of sigma by facilitating nucleation. However, Lena and Curry[25] have recently

suggested that the increased rate of sigma formation in cold-worked 25% Cr—20%Ni austenitic steels which do not form ferrite during cold working can be attributed to a recrystallisation transformation according to the following equation:

Strained austenite of composition $C_1 \longrightarrow$ sigma + unstrained austenite of composition C_2

If the conditions of deformation and ageing temperature are such that recrystallisation does not occur, then the accelerating effect of cold work is at most very small. The recrystallisation transformation results in at least two morphological forms of sigma. One of these is similar to pearlite with alternate plates of sigma predominantly at the recrystallised grain boundaries. This latter form is favoured by rapid recrystallisation rates with a resultant fine grain size such as is obtained with moderately worked samples aged at cold temperatures, or heavily cold worked samples aged at moderate temperatures.

Limited information[26, 27] suggests that stressing a fully austenitic 18% Cr—12%Ni niobium-stabilised steel, initially annealed at 1,050°C., also accelerates the sigma precipitation process at 650°C.

Goldschmidt[28] and Lismer, Pryce and Andrews[20] have suggested that sigma forms from austenite *via* the precipitation of $M_{23}C_6$ which is rich in chromium. Evidence of this type of reaction and some new features have recently been observed by Pickering[23] in an optical and electron microscope study of a fully austenitic 25%Cr—15%Ni steel.

Table 3. Sigma formation and its effect on the hardness of a 25% Cr—20%Ni austenitic steel[11]

Annealing treatment, °C.	*Sigma, %*	*Hardness V.P.N., 30-kg. load*
As softened	Nil	150
650	Trace	163
700	2	167
750	5	174
800	6	167
850	6	167
900	1	157
950	Nil	154

Room temperature properties

The effects of sigma formation on the room temperature tensile and impact properties of a series of austenitic steels are shown in Table 4. In general, sigma appears to have little influence on the proof and ultimate tensile stresses, but causes a reduction in the ductility values in tensile tests and a marked drop in impact values.

The extent of the room temperature embrittlement is not only related to the amount of sigma present but also to the distribution which depends on grain size. For example, the sigma in the fine-grained 25%Cr—20%Ni steel (steel 3) is produced as a massive precipitate at the grain boundaries. In coarse-grained samples of the same steel sigma contents less than 5% are precipitated as a semi-continuous grain boundary film, but larger amounts are formed as acicular precipitates within the grains. The sigma forms more slowly in the coarse-grained specimens but the rate of embrittlement is greater. The results suggest that the grain boundary σ in the coarser-grained steels is more harmful and accounts for the greater embrittlement of the coarser-grained steel for equivalent σ contents.

The embrittlement of the coarse-grained, fully austenitic 25%Cr—20% Ni steel (steel 3) is partially due to the precipitation of carbides during the initial stages of reheating at 800°C. At 1,150°C. the chromium carbides are soluble in the austenite, but precipitate out of solution mainly at the grain boundaries during the first 24 hr. at 800°C. The carbide precipitation produces slight increases in the proof and ultimate tensile stresses and reductions in the tensile ductility and impact values. However, embrittlement due to the carbide precipitation is small when compared with that produced by the sigma formation.

Elevated temperature properties

The high-temperature tensile ductility and impact properties of a series of steels before and after sigmatising are shown in Table 5. Whereas the presence of sigma in the fully austenitic steels 5 and 6 still causes a decrease in the high-temperature ductility, the reduction, with the exception of steel 6 tested at 870° and 980°C,

Table 4. Effect of sigma on the room temperature tensile and impact properties

Steel	*Analysis, %*								*Initial heat treatment*	*Grain size A.S.T.M. No.*	*Ageing temp., °C.*	*Ageing time*	*Microstructure*	*0.5% P.S. tons/sq.in.*	*U.T.S. tons/sq.in.*	*Elongation %*	*R. of A., %*	*Impact energy ft.lb.*	*Ref.*
	C	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	*Nb*	*Ti*											
1	0.11	0.50	0.41	9.50	17.84	0.05	1.22	—	1,050 °C. Air cool	7—8	650	—	γ + C	17.0	39.9	57	65	117*	26
												1 Month	γ + C	19.8	41.0	56.5	63.5	116	
												3 Months	γ + C	18.9	39.9	54.5	63.5	96	
												1 Year	γ + C + 2% σ	18.75	40.7	50.0	57.5	60	
												2½ Years	γ + C + 3.5% σ	18.18	40.25	48	53	38	
												7½ Years	γ + C + 4% σ	18.3	40.25	47	50	33	
2	0.12	0.78	1.41	12.13	18.46	0.017	1.33	—	1,050 °C. Air cool	7—9	650	—	γ + C	17.15	39.2	56	65	119*	26
												1 Month	γ + C	18.45	40.6	51	59	82	
												3 Months		17.75	40.0	52	60	82	
												1 Year	γ + C + 3% σ	17.4	40.3	46	53	45	
												4 Years	γ + C + 5% σ	19.2	44.0	34	35	21	
3	0.14	1.30	0.6	20.9	25.0	—	—	—	1,050 °C. Air cool	7—8	800	—	γ + C	22.1	43.8	50	61	113†	11
												350 hr.	γ + C + 6% σ	20.5	42.1	31	25	12	
												1,000 hr.	γ + C + 12% σ	21.0	41.0	20	17	6	
												8,000 hr.	γ + C + 14% σ	20.9	35.9	19	14.5	5	
									1,150 °C. Air cool	3—5	800	—	γ	18.6	42.8	58	65	120†	11
												24 hr.	γ + C	22.5	45.7	44	51	55	
												350 hr.	γ + C + 4% σ	20.9	43.7	20	17	5	
												1,000 hr.	γ + C + 8% σ	21.1	35.0	6	4	3	
												8,000 hr.	γ + C + 14% σ	22.3	29.5	3	1	1	
4	0.07	0.62	0.86	9.4	18.7	0.28		0.60	1,050 °C. Air cool	9—10	600	—	γ + C + F	24.5	46.5	53	67	56‡	29
												7 days	γ + C + F + σ	27.1	46.0	56	73	44	
												33 days	γ + C + F + 3.1% σ	20.1	42.8	42	60	42	
												84 days	γ + C + 3.8% σ	22.7	44.0	38	55	35	
											700	—	γ + C + F	24.5	46.5	53	67	56‡	
												7 days	γ + C + F + 4% σ	21.5	43.0	41	65	33	
												28 days	γ + C + F + 4.5% σ	20.5	42.1	41	50	24	
												84 days	γ + C + 6% σ	23.0	44.0	45	50	20	

γ = Austenite; C = carbide; F = Ferrite; σ = sigma *Charpy V-notch impact tests †'Izod' impact tests ‡Subsize Charpy V-notch impact tests

Table 5. Effect of sigma on elevated temperature tensile ductility and impact properties

Steel	Analysis, % C	Si	Mn	Ni	Cr	Mo	Nb	Ti	Initial heat treatment	A.S.T.M. grain size	Ageing temp., °C.	Ageing time	Microstructure	Test temp., °C.	Elongation, %	R. of A., %	Impact energy, ft.lb.*	Ref.
4	0.07	0.62	0.86	9.4	18.7	0.28		0.60	1,050°C. A.C.	9—10			γ + F + C	R.T. 600 700	53 20 22	67 57 76	56 73 75	29
											600	84 days	γ + C + 3.8% σ	R.T. 600 700	38 18 22	55 48 55	36 45 44	
											700	84 days	γ + C + 6% σ	R.T. 600 700	45 15 18	50 45 60	20 28 32	
5	0.07	1.15	1.08	22.0	23.7	0.11	—	—	1,050°C. A.C.	7—8	—	—	γ + C	R.T. 600 700	39 23 27	48 37 42	48 43 42	29
											600	84 days	γ + C	R.T. 600 700	34 24 25	45 37 42	34 34 33	
											700	84 days	γ + C + δ% σ	R.T. 600 700	26 20 21	32 35 35	9 13 15	
6	0.059	1.88	1.96	21.24	24.62	—	—	—	1,100°C. A.C.	2—3	—	—	γ + C	R.T. 540 650	42 47 30			24
														760 870 980	47 60 80			
											870	200 hr.	γ + C + σ	R.T. 650 760	2 5 25			
														870 980	14 25			

*Substandard Charpy V-notch impact tests γ = Austenite; C = Carbide; F = Ferrite; σ = sigma

it is not as marked as at room temperature. Steel 6 possessing a much coarser grain size is embrittled to a greater extent than steel 5, which has a fine grain size. This is again associated with a difference in the mode of the sigma precipitate in the two steels. The fine-grained steel (steel 5) showed a massive precipitate at the grain boundaries, whilst the coarse-grained steel (steel 6) exhibited grain boundary films and Widmanstatten precipitates of sigma.

In general, the 600° and 700°C. tensile ductilities of the duplex steel (steel 4) are affected to a lesser extent than the room temperature ductility. In contrast, increasing the temperature of test from room temperature to 600° or 700°C. slightly increases the extent of the embrittlement as gauged by the impact results. However, this is offset by the higher impact energy values at the elevated temperatures before and after sigmatising.

Creep properties

Only a limited amount of data is available regarding the effect of sigma on the creep resistance of steels. The results of short-time creep tests (100-hr. duration) on a 25%Cr—20%Ni austenitic steel are shown in Table 6.[24]

At times corresponding to the slower strain rates (low stresses) and particularly at the higher temperatures, above 650°C., a decrease in creep strength can be associated with the presence of sigma. A decrease in the long-time creep and rupture strength at 815°C. of a sigmatised 25%Cr—12%Ni steel has also been observed, but the decrease was not as pronounced as shown in Table 6 because only a small quantity of sigma was formed.[30]

Table 6. Creep test results on 25%Cr—20%Ni steel[24]

Condition	Microstructure	Time, min.	Stress for 1% permanent deformation × 10^3 p.s.i. 650°C.	760°C.	870°C.	980°C.
1,095°C. 30 min. Air cooled	Austenite and carbide	10	24	18	10	5.2
		100	23	14.5	7.5	4.0
		1,000	20	12	5.8	3.5
		5,000	18	10	4.8	3.2
1,095°C. 30 min. Air cooled plus 200 hr. at 870°C.	Austenite and carbide and sigma	10	37	18	9	5.2
		100	29	12.5	6.5	3.8
		1,000	21	8.6	4.7	—
		5,000	16	6.5	3.4	—

In analysing the creep results obtained on the initially austenitic structures it should be borne in mind that they gradually become sigmatised during the course of the test. It is likely, therefore, that the stresses for 1% permanent deformation are reduced slightly, relative to the values which would exist if the initial austenitic structure could be preserved during the whole course of the creep test. More recent work by Hum and Grant[31] and Monkman *et al.*[32] has established that the formation of massive sigma markedly affects the creep rupture properties of 18%Cr—8%Ni type austenitic steels. The initial precipitation of sigma at the grain boundaries of the austenite results in an improvement in the properties, but the subsequent growth of this phase has a detrimental effect on the high-temperature strength.

Thermal fatigue

Sigma-free alloys are much less susceptible to cracking and distortion than sigma-bearing alloys in thermal fatigue tests.[33] Thermal fatigue tests were made on two cast 26%Cr—12% Ni steels with their compositions slightly adjusted so that the first steel consisted of austenite and carbides and the second, austenite, a moderate amount of sigma and carbides after heat treatment. Alternate heating at 870°C. and rapid cooling produced cracking in the sigma-bearing alloy

after only 39 cycles and the specimen split in two after 161 cycles. The sigma-free alloy did not crack until 472 cycles of test.

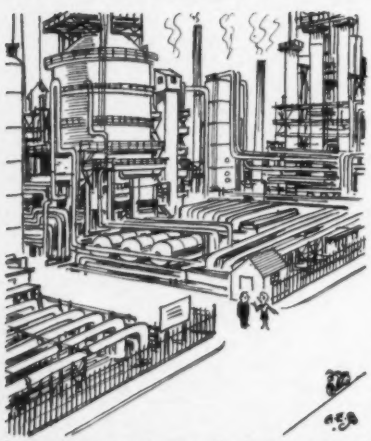
Corrosion resistance

Little is known about the influence of sigma phase on the corrosion resistance of austenitic steels other than in acid solutions. It has been established that the sigma phase can cause accelerated corrosion in boiling 65% nitric acid and in hot, concentrated (40 to 80%) sulphuric acid solutions. There has been no evidence to indicate that sigma phase is necessarily deleterious to the corrosion resistance in other media. Moreover, there are no records of failures of austenitic steel structures that can be definitely attributed to the presence of sigma.

The form and distribution of the sigma phase determines the effect on the corrosion resistance in 65% nitric acid. Sigma phase in the form of an envelope of fine particles around the grains will cause severe intergranular corrosion,[34, 35, 36] but when the sigma phase is coalesced in the form of isolated pools in the grain boundaries, it has no effect on the nitric acid corrosion resistance.[37, 38] In the case of an 18%Cr—8%Ni—3%Mo—1%Ti steel, boiling 65% nitric acid preferentially attacks ferrite which has been partially transformed to sigma phase.[39, 40] However, with complete transformation of the ferrite to the sigma phase, the nitric acid attack is greatly reduced.

When sigma is present in 18%Cr—8%Ni—3%Mo—1%Ti steel the corrosion rate in 25% sulphuric acid at 40°C. is about 12 times that for the steel in the annealed condition.[15] In this instance about half of the original ferrite content (40%) had been transformed to sigma phase by heating for 4 hr. at 750°C. It has also been observed that in less corrosive media such as 5% sulphuric acid at 40°C. or acidified ammonium sulphate solution, there is no decrease in corrosion resistance due to sigma phase.[15, 40] Further, the sigma phase may seriously increase the corrosive attack in hot, strong (40 to 80%) sulphuric acid, but it is generally not harmful in more dilute (1 to 5%) hot, sulphuric acid solutions.[41]

COMICAL ENGINEERING CORNER



"I WONDER IF YOU COULD HELP ME?—I'M OUT OF PETROL"

Of interest to our readers . . .

A number of articles appearing in our associate journals this month will appeal to readers of CHEMICAL & PROCESS ENGINEERING.

Manufacturing Chemist—Lighting for Chemical Laboratories and Factories, by R. T. O. Freeth. Research in the British Pharmaceutical Industry and the Control of Tropical Diseases, by E. C. Wilmshurst. Fertilisers and Plant Nutrients, by D. P. Hopkins. Disinfectants, by A. H. Walters.

Petroleum—Impact of Recently Developed Processes on Refining Technology, by R. C. Kersten and G. F. Asselin. Germany's Growing Petroleum Industry.

Food Manufacture—Special Feature on Packaging. Use of Glyceryl Monostearate, by E. S. Lower.

Automation Progress—Modern Digitising Techniques (part 2), by E. M. Deesly. Control of Space Heating, by E. R. Ashford.

Paint Manufacture — Oxidised Rubber in Paints, by G. Speight. The Moscow Symposium on Macromolecular Chemistry, by H. Warson.

Fibres and Plastics—Properties of Reinforced Plastics, by I. L. Hepner. Japan's Chemical Fibres, by R. W. Moncrieff.

Corrosion Technology—Sprayed Metal and Plastic Coatings, by J. H. Nicholls. Zinc Silicate Spraying, by N. R. MacCleaster. Developments in Organic Protective Coatings, by J. K. Aiken and S. W. Critchley.

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CHEMICAL PLANT COSTS

Cost indices for the month of July 1960 are as follows:

Plant Construction Index: 181.1

Equipment Cost Index: 170.6

(June 1949 = 100)

£ s d

Thermal Conduction and its Special Application to Thermal Insulation

By H. K. Suttle,* M.I.Chem.E., F.R.I.C., M.Inst.F.

'The effects of heat are subject to constant laws which cannot be discovered without the aid of mathematical analysis. The object of the theory which we are about to explain is to demonstrate these laws . . .'. So wrote J. B. Fourier, pioneer of the science of heat. The author, an eminent chemical engineer with long experience in heat-transfer science and technology, describes in this article the broad conceptions of the theory of heat transfer, thermal conduction and its application to thermal insulation. This presentation should be of special importance to practising engineers whilst serving as an inducement to those interested in further study.

THE extract quoted in the preamble, taken from ' Théorie Analytique de la Chaleur ',[1] by J. B. Fourier, would seem to the writer to express elegantly the nature of the task allotted to him, were it not apparent that space and the tolerance of the reader preclude this lengthy approach to the subject. It is consoling, however, to read the following observations by Fourier, taken from the *prolegomena* to his work: ' The problems of the theory of heat present so many examples of the simple and constant dispositions which spring from the general laws of nature; and if the order which is established in these phenomena could be grasped by our senses, it would produce in us an impression comparable with the sensation of musical sound. The forms of bodies are infinitely varied; the distribution of heat which penetrates them seems to be arbitrary and confused; but all the inequalities are rapidly cancelled and disappear as time passes on. The progress of the phenomenon becomes more regular and simpler, remains finally subject to a definite law which is the same in all cases, and which bears no sensible impress of the initial arrangement '.

It is clear that the interpretation of experimental observations by a method of mathematical analysis is the means by which a hypothesis, based on observation, may be transformed to a law which will have a universal application.

In experiments on heat conduction between two planes, contained in a mass of material of uniform structure, each plane being retained at definite temperatures so that a steady state is secured, it is well understood that the quantity of heat (Q) which flows through the plane surface of area (A) in time (θ) is given by the expression

$$Q = \frac{k(t_1 - t_0)A\theta}{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

in which t_1 and t_0 are the temperatures at the respective positions of the planes considered, also t_1 has a larger value than t_0, and x is the distance between the planes.

The apparent conclusion is that the flow of heat for this case is proportional to the value of $(t_1 - t_0)$. Such an experiment does not establish any law, neither does it justify the conclusion mentioned. This is an example of a hypothesis which requires some further test before the concept can be accepted as true.

Thermal conductivity

The thermal conductivity of the material is denoted by k. This is often simply explained as the proportionality constant which allows of a balance between both sides of equation (1). It has a numerical value which is rarely constant, as it varies with temperature, although for a limited temperature range an average, constant, value may be used with considerable confidence. However, there are examples where more precise information is required and in these cases the variation in the value of k may often be expressed conveniently by means of the expression

$$k = k_0 (1 + \beta t)$$

in which k_0 represents the conductivity at a base temperature and β is a constant, which is always small and may be a positive or a negative value. It has been shown[2] that a typical insulating material may possess qualities which show a variation in k according to the empirical formula, $k = at^2 + bt + c$, in which a, b and c are constants. Appendix 1 presents typical examples and, in addition, shows the effect of varying conditions of use and manufacture.

Transformation of equation (1) will show the nature of the units and dimensions of thermal conductivity as follows

$$k = \frac{Qx}{(t_1 - t_0)A\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The unit of heat is conventionally taken to be that quantity which brings about unit rise in temperature in a unit mass of water. In the usual English engineering system, this quantity is the British Thermal Unit (B.Th.U.). Examined dimensionally, in the L.M.T. system of dimensions, there may be written

$$[Q] = [M]\,[t_1 - t_0] \text{ or } [Q/(t_1 - t_0)] = [M]$$

Whence it follows that the dimensions of k are given by

$$k = [M]\,[L^{-2}]\,[T^{-1}] \quad \ldots\ldots\ldots\ldots\ldots \quad (2a)$$

In conventional chemical engineering practice the basis of T is 1 hr., and that of thickness (x) is 1 ft. It is convenient

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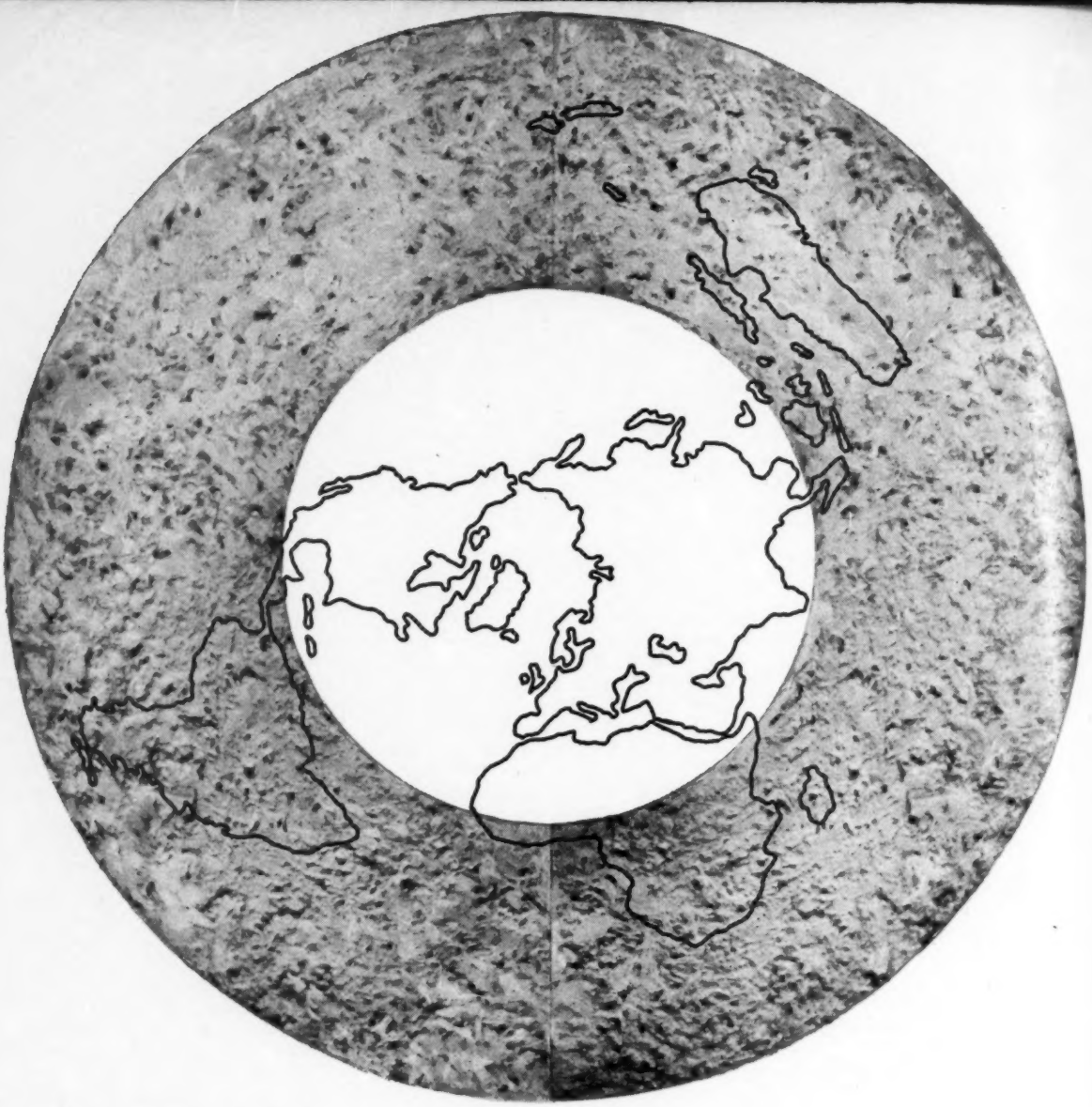

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to conduct calculations in heat insulation technique on the basis of a thickness of 1 in., so that the value of k would be expressed as B.Th.U./(sq.ft.)(hr.)(°F./in. thickness).

Occasionally the quantity of heat is measured by the work necessary to produce it, in which case the unit of measurement would be the erg or the joule.

If the solid is homogeneous so that the heat 'spreads out equally in all directions' from a heated point within it, the solid is said to be isotropic. In contrast to this, anisotropic (and crystalline) bodies possess structures which make certain paths more favourable to heat conduction than others. Heterogeneous solids present conditions such that the conduction varies not only in direction but also from point to point within the mass.

The majority of modern heat-insulating materials are fabricated in such a manner as to include air pockets, or the naturally occurring mineral assumes this form. It has been shown[2] that glass fibres compressed into a block, and so entrapping a large number of air pockets, have a thermal conductivity only 5% of the value of the solid glass, due to the extremely low thermal conductivity of the air contained in the insulating mass. Examples of materials of this type are formulations of diatomaceous silica—asbestos—and exfoliated vermiculite.

Heat flux

The flux of heat is defined as the rate at which heat is transferred across a surface, at a selected point, for a unit area in unit time. Carslaw and Jaeger[3] denote this quantity by the symbol f, as will be used here. (Chemical engineers will often use the term (q/A) in which q represents heat quantity/unit time.) Thus, f has the units B.Th.U./(sq.ft.)(hr.) in normal engineering use. The consideration is an infinitesimally small area, which encloses a point O, taken anywhere inside an isotropic solid, the thermal properties of which are finite. The small area is considered to be one end of a tiny cylinder having a length much less than the dimension of the area. As this length is considered to diminish almost to vanishing point, it may be shown that the fluxes at each end surface become the same

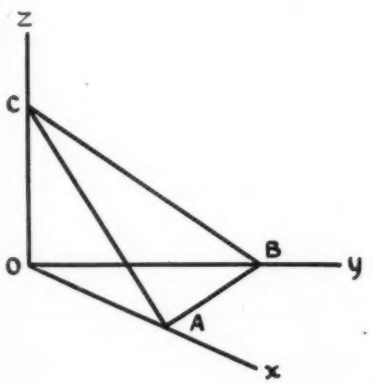


Fig. 1

value. That is, the heat flux is continuous. This being so, the question to be resolved is if the values of f are known for three mutually perpendicular planes meeting at the point O, can the value of the heat flux for any other plane through that point be found? The treatment of this problem is as follows,[3] based on vector methods.[4] From the origin O, the point under consideration, on the three Cartesian axes OX, OY, OZ, are the three planes OAC, OBC and OAB. Fig. 1 illustrates this condition, and interest centres on the face ABC. A perpendicular drawn from point O to the surface ABC will have length x and has *direction cosines* (λ, μ, ν). Following the authors of reference 3, the area of ABC may be designated Δ, when the areas OBC, OAC and OAB are respectively $\lambda\Delta$, $\mu\Delta$ and $\nu\Delta$. The heat fluxes over the same elementary areas, and in the same order, are denoted by f_x, f_y and f_z, and for the face ABC the term is simply f. Heat is gained by the whole elementary tetrahedron $OABC$ at a rate which is shown by

$$(\lambda f_x + \mu f_y + \nu f_z - f)\Delta$$

If the average temperature of this small element of solid is t, the density ρ, and the specific heat denoted by c, then the rate of gain of heat is also given by the expression

$$\tfrac{1}{3}\,\Delta \,.\, x \,.\, \rho \,.\, c \,.\, \frac{\partial t}{\partial \theta}$$

that is

$$\lambda f_x + \mu f_y + \nu f_z - f = \tfrac{1}{3}\, x\rho c\, \frac{\partial t}{\partial \theta} \quad \ldots\ldots\ldots \quad (3)$$

As the length x tends to zero, the right-hand side of equation (3) tends to zero also and the terms f_x, f_y, f_z and f become respectively the fluxes at point O across planes which are parallel to the co-ordinate planes and across a plane through O which has λ, μ and ν for the direction cosines to its normal. Thus there may be written

$$f = \lambda f_x + \mu f_y + \nu f_z \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

Equation (4) provides the means by which the flux through any plane passing through O may be found when the other three fluxes are known.

At every point (O) in the solid a vector may be conceived, the components of which will be f_x, f_y and f_z and which will have a magnitude defined by

$$f_m = \sqrt{(f_x^2 + f_y^2 + f_z^2)} \quad \ldots\ldots\ldots\ldots \quad (5)$$

This vector $(\boldsymbol{f})$ lies along the line which has direction cosines f_x/f_m, f_y/f_m and f_z/f_m and is termed the flux vector at the point O. Thus it will be seen that the flux at a point such as (O) across a plane whose normal lies exactly in the direction of $\boldsymbol{f}$ is simply f_m, but if the flux is considered across a plane whose normal makes an angle φ with this direction its value would then be $f_m \cos \varphi$.

Considerations in this manner lead to the conception of the isothermal surface, and the solid may be imagined to be divided up into hypothetical thin shells by means of its isothermals. Although such surfaces may be arranged in any manner they must never cross one another, for this would imply that a portion of the body could have two temperatures at the same time. Computation by graphical methods[5] and relaxation methods,[6] as well as analogue models,[7] have as their basis this conception of the isothermal surface.

Mathematical theory of heat conduction

The nature of an isotropic solid is such that the flux vector at a point within it will be normal to the isothermal surface through that point. In addition, it will lie in the direction of falling temperature. Interest centres on the rate of change of temperature along this normal to the isothermal and, indeed, the flux vector in that direction may be deduced from a simple experiment such as that described by equation (1). Let the isothermals be planes parallel to the faces of a slab of isotropic solid, then these will exist for temperatures t and $t + \delta t$ and will be considered a distance δx apart. According to equation (1) the rate of flow of heat (per unit time/unit area) in the

direction of x (*i.e.* x is increasing) will be given by

$$-k\frac{\delta t}{\delta x}$$

and, in the limit, as δx tends to zero,

$$f_x = -k\frac{\partial t}{\partial x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

This, of course, may be extended to any isothermal surface and leads to the definition of the mathematical theory of the subject, which is succinctly stated as follows:[3] The rate at which heat crosses from the inside to the outside of an isothermal surface (per unit time/unit area) is equal to

$$-k\frac{\partial t}{\partial n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

In this relation, k denotes thermal conductivity and $\partial/\partial n$ denotes differentiation along the outward-drawn normal to the surface. This expression is to be regarded as the fundamental hypothesis of the theory, and the requirement is now to extend this to show the flux at the point O across any surface, which is not necessarily isothermal. This is accomplished by the methods of differential geometry, when it is shown that the same expression (7) applies. It should be especially noted that the fluxes across three planes parallel to the co-ordinates are given by

$$f_x = -k\frac{\partial t}{\partial x}; f_y = -k\frac{\partial t}{\partial y}; f_z = -k\frac{\partial t}{\partial z}$$

or, in terms of vectors, they are expressed by

$$\boldsymbol{f} = -k \text{ grad } t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

When heat energy flows through a solid, some of this energy may be stored or heat may be developed within the mass. A rigorous mathematical treatment of the subject will take all these aspects into account. It is conveniently considered for the case of an isotropic solid in which there is no heat generation, for, in such a material the temperature at the point O (x, y and z) will be expressible as a continuous function of the co-ordinates x, y and z and of time. The same will apply to the flux of heat.

A rectangular parallelepiped of differential size, having the point O at its centre, is conceived within the mass of the substance. The edges are considered parallel to the co-ordinate axes and may be assumed to have lengths 2 dx, 2 dy and 2 dz, respectively, as shown in Fig. 2. Energy flows into the volume over the face $ABCD$, and the surfaces are at the planes $x - dx$ and $x + dx$, respectively. The rate at which the heat enters is given by

$$4\left(f_x - \frac{\partial f_x}{\partial x}dx\right)dy\,dz$$

and flows outwards over the opposite face at the rate

$$4\left(f_x + \frac{\partial f_x}{\partial x}dx\right)dy\,dz$$

That is, the rate of gain of heat is given by

$$-8\,dx\,dy\,dz\,\frac{\partial f_x}{\partial x}$$

When this process is repeated for the other pairs of faces, and the respective values are added, there results

$$-8\left(\frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y} + \frac{\partial f_z}{\partial z}\right)dx\,dy\,dz$$

that is

$$-8\,dx\,dy\,dz \text{ div } \boldsymbol{f} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

f_x is the heat flux at O over a parallel plane, at that location.

Equation (9) may also be equated with the corresponding expression for the gain of heat, namely,

$$8\,\rho c\frac{\partial t}{\partial \theta}\,dx\,dy\,dz \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

to yield the relation

$$\rho c\frac{\partial t}{\partial \theta} + \left(\frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y} + \frac{\partial f_z}{\partial z}\right) = 0 \quad \ldots\ldots \quad (11)$$

It will be apparent that this equation must hold for any point in the solid, and a little consideration will show that the solid need not necessarily be isotropic or homogeneous.

For a typical isotropic solid, the value of the thermal conductivity (k) may be regarded as a constant value. That this is so for a homogeneous body over narrow ranges of temperature is well known. Thus the values of the several fluxes may be introduced, by reference to equation (8), and equation (11) may be written as

$$\rho c\frac{\partial t}{\partial \theta} = k\left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right) \quad \ldots\ldots \quad (12)$$

or

$$\frac{\partial t}{\partial \theta} = \alpha\left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right) \quad \ldots\ldots\ldots \quad (13)$$

in which the quantity (α) is given by $k/\rho c$, the '**thermal diffusivity**'. Equation (13) is commonly known as the '**equation of heat conduction**'.

Thermal diffusivity

In engineering units, the term α is expressed as sq.ft./hr. The term '**diffusivity**' (so named by Kelvin) is analogous to the same quantity discussed in other transport processes of chemical engineering, although the term '**thermometric conductivity**' (suggested by Clerk Maxwell) would appear to describe more graphically its use in heat-transfer processes. Examination of equation (13) will show that α is a measure of the change of temperature which is produced per unit time in a unit volume of the substance, having a unit temperature difference between the faces through which the quantity of heat is flowing. As discussed above,

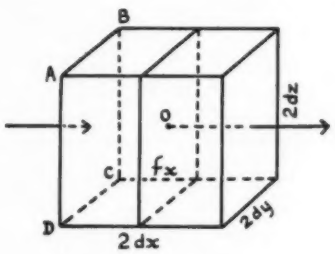


Fig. 2

the basis is that of a unit area and a unit thickness between the respective surface layers.

If the boundary conditions are arranged so that the temperatures are steady (that is, t does not vary with time), equation (13) assumes the form of Laplace's equation, namely,

$$\nabla^2 t = \frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} = 0 \quad \ldots\ldots\ldots \quad (14)$$

which is easily seen if equation (13) is written in the form

$$\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} - \frac{1}{\alpha}\frac{\partial t}{\partial \theta} = 0 \quad \ldots\ldots \quad (13a)$$

Heat generation within body

The principles discussed may now be extended to the topic in which heat is developed, or generated, within the solid. These cases are becoming of increasing importance in modern technology, for instance in induction heating, radioactive decay, chemical reaction and electrical heating methods. The problem may not arise directly, however, in the usual methods employed in heat insulation.

The heat generated, /unit volume/unit time, at the point $O\ (x, y, z)$ may be designated $q^{\star}$. This term is added to equation (12), or the term $q^{\star}/\rho c$ is added to equation (13). When introduced into equation (13*a*) the constant value k appears, as shown,

$$\nabla^2 t - \frac{1}{\alpha}\frac{\partial t}{\partial \theta} = -\frac{q^{\star}}{k} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

For the condition that the temperature does not vary with time, $\partial t/\partial\theta$ becomes zero, and equation (15) reduces to Poisson's equation.

For prescribed boundary conditions of heat flux or temperature, and also where the values of ρ, c and k are constant, equations (12) to (15) lead to solutions of problems in steady-state heat flow. A problem in heat conduction must, therefore, satisfy Fourier's equation, equation (13), either as given or with appropriate modifications, to be mentioned later. The concern, then, is the determination of t as a function of the co-ordinates of both space and time, and each problem has characteristics which are peculiar to that investigation. For example, when the initial conditions are laid down it is implied that when θ is zero the temperature throughout the body, expressed as a function of the space co-ordinates, will be given by $t = \varphi\ (x, y, z)$. The boundary conditions vary according to the type desired, for it may be considered that $t = \psi\ (x, y, z, \theta)$—a function of position, time, or both these. At the surface of separation of two media the heat flux is continuous (refer to equation 7) and

$$k_1(\partial t_1/\partial n) = k_2(\partial t_2/\partial n)$$

and, similarly, the boundary surface is impervious to heat, or $(\partial t/\partial n) = 0$. When losses due to radiation and convection occur at the surface, there may be written, for the steady state, $-k(\partial t/\partial n) = ht$, in which h represents the rate of heat loss by radiation and convection per unit area of surface for each degree above the temperature of the environment.

It has been remarked that, if the medium is not homogeneous, then the thermal conductivity will have values which vary in different planes, as, for example, k_x, k_y and k_z, in the directions x, y and z. Equation (15), written in the form of equation (12), then assumes the form

$$\rho c\frac{\partial t}{\partial \theta} = k_x\frac{\partial^2 t}{\partial x^2} + k_y\frac{\partial^2 t}{\partial y^2} + k_z\frac{\partial^2 t}{\partial z^2} + q^{\star} \ldots. (16)$$

This leads to the general case, where the thermal conductivity is a function of temperature, and the term $k(\partial^2 t/\partial x^2)$ becomes

$$\frac{\partial}{\partial x}\left(k\frac{\partial t}{\partial x}\right)$$

The expression showing these conditions is as follows

$$\rho c\frac{\partial t}{\partial \theta} = \frac{\partial}{\partial x}\left(k_x\frac{\partial t}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y\frac{\partial t}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z\frac{\partial t}{\partial z}\right) + q^{\star} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

The simple solutions which will now be discussed serve to illustrate the foregoing commentary, and will show how many industrially important problems may be resolved without recourse to complex mathematical procedures.

The common example is that of heat flow through a thin plate, or along a rod. The edges of the plate, or the rounded surface of the rod, are assumed to be perfectly insulated and the temperatures at the surfaces of the plate are retained constant at t_1 and t_2, respectively. The condition visualised is that of an infinitely wide plane plate, of uniform conductivity, and it is assumed that the heat flows in one direction only, for example the x-direction. It will be noted that this case represents also a steady heat flow in any such body if the isothermal surfaces are parallel planes. In addition, it is assumed that no heat is generated within the material.

It will be seen, from Fourier's equation, that $\partial t/\partial\theta = 0$ and also $q^{\star}$ and $(q^{\star}/\rho c) = 0$. There remains the Laplace equation to describe the condition, but as heat flows only in the x direction then $\partial^2 t/\partial y^2 = 0$ and $\partial^2 t/\partial z^2 = 0$. Thus, for these cases, the general equation of conduction reduces to

$$\frac{d^2 t}{dx^2} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

and the ordinary derivative is used, rather than the partial derivative which has no significance in this case. Equation (18) is, then, the differential equation which represents the temperature distribution across an infinitely extended plate when the heat flows in one direction only. Equation (18) is easily handled, for integration gives

$$t = Mx + N \quad \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

where, it will be noted, x represents the distance from some arbitrary plane. The boundary conditions are now stated, as follows, for it may be conceived that

at point $x = x_1$, $t = t_1$
whereas at point $x = x_2$, $t = t_2$

Substitution in equation (19) is easily done to yield the two expressions, $t_1 = Mx_1 + N$ and $t_2 = Mx_2 + N$. The values of the integration constants are now found to be

$$M = \frac{t_1 - t_2}{x_1 - x_2} \quad \text{and} \quad N = \frac{t_2x_1 - t_1x_2}{x_1 - x_2}$$

Thus the temperature at any point in the plate at a distance x from the plane yz is given by

$$t = \frac{t_1 - t_2}{x_1 - x_2}x + \frac{t_2x_1 - t_1x_2}{x_1 - x_2} \quad \ldots\ldots\ldots\ldots (20)$$

The rate of flow of heat is given by $q = dQ/d\theta$, and from equation (1)

$$q = -kA\frac{dt}{dx}$$

The value for t given by equation (20) is substituted and the differentiation performed, to yield the well-known relation

$$q = -kA\frac{t_1 - t_2}{x_1 - x_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (21)$$

or the heat flux

$$f = -k\frac{t_1 - t_2}{x_1 - x_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (22)$$

Thermal resistance

The value of q must, of course, be a positive quantity and it is customary in technology to ignore the minus sign. With this modification, equation (21) may be written

$$q = k\frac{A\,\Delta t}{x} = \frac{\Delta t}{x/kA} \quad \ldots\ldots\ldots\ldots\ldots (21a)$$

and the quantity x/kA is termed the thermal resistance, denoted by R. A useful form of this equation is thus

$$q = \frac{\Delta t}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

and, by analogy with the current equation in electrical technology, serves to show that heat is transferred through a resistance by reason of a ' driving force ' or ' potential ', shown by the temperature difference. The concept is particularly useful when the rate of heat flow is to be computed through composite walls, where the several layers may be of different thickness composed of materials having different conductivities. When the several layers are in ' thermal contact ' the situation is that of conductivity in series fashion. For such a case, equation (23) could be

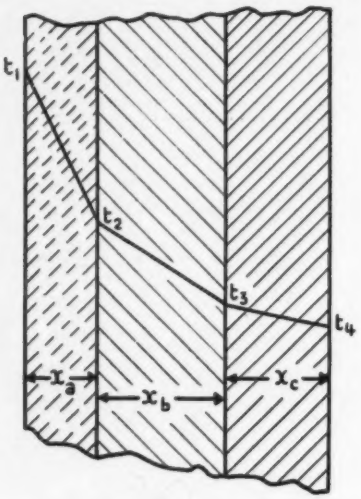


Fig. 3

written for each section. Fig. 3 serves to illustrate the operation for the continuous heat flow through a composite wall, having a high temperature (t_1) at one side and a steady, but lower, temperature (t_4) at the other side. It will be apparent that

$$q = \frac{t_1 - t_2}{R_a} = \frac{t_3 - t_2}{R_b} = \frac{t_4 - t_3}{R_c}$$

$t_1 - t_2 = qR_a$, $t_3 - t_2 = qR_b$ and $t_4 - t_3 = qR_c$. The sum of these yields the expression

$$t_4 - t_1 = q(R_a + R_b + R_c) = qR \quad \ldots. \quad (24)$$

or

$$q = \frac{t_4 - t_1}{R} = \frac{t_4 - t_1}{(x_a/k_aA_a) + (x_b/k_bA_b) + (x_c/k_cA_c)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (25)$$

which may be written in the following general form, for the temperature extremes t_m and t_n,

$$q = \frac{t_m - t_n}{\int_n^m \frac{dx}{kA}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (26)$$

If a wall is built up of materials of different conductivity arranged in parallel, the concept of thermal resistance is again valuable in calculating heat flow. For this case, assuming the temperature extremes to be t_m and t_n, with heat flow quantities of q_1 and q_2 for the example of two materials,

$$q_1 = \frac{t_m - t_n}{R_a} \qquad q_2 = \frac{t_m - t_n}{R_b}$$

The total heat flow (q) is given by

$$q = q_1 + q_2 = \frac{t_m - t_n}{R} \quad \ldots\ldots\ldots\ldots \quad (27)$$

in which the value of R is given by

$$R = \frac{R_aR_b}{R_a + R_b}$$

Heat flow in sphere

The general theory of heat conduction will now be extended to the cases of the sphere and the cylinder, that is, heat flow in more than one dimension and with steady-state conditions.

This implies that the heat conduction equation must be transformed to polar co-ordinate form,[3] although this may be secured also by the methods of formal differentiation.[5, 7] The nature of the spherical/co-ordinate system will be seen from Fig. 4. The distance of the point of interest is found from its distance r from the origin, the latitude ξ and its azimuth ζ. In addition, the relation between the rectangular/ and spherical/co-ordinate systems is given by

$$x = r\cos\zeta\sin\xi \qquad y = r\sin\zeta\sin\xi \qquad z = r\cos\xi$$

The length of arc s is given by

$$ds^2 = dr^2 + r^2d\xi^2 + r^2\sin^2\xi d\zeta^2$$

By a method similar to that used for the derivation of equation (12) the conduction equation becomes

$$\frac{\partial t}{\partial\theta} = \frac{\alpha}{r^2}\left[\frac{\partial}{\partial r}\left(r^2\frac{\partial t}{\partial\theta}\right) + \frac{1}{\sin\xi}\frac{\partial}{\partial\xi}\left(\sin\xi\frac{\partial t}{\partial\xi}\right) + \frac{1}{\sin^2\xi}\frac{\partial^2 t}{\partial\zeta^2}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

The equation is rather more graphic if a term $\mu = \cos\xi$ is introduced, as shown by Carslaw and Jaeger, as follows

$$\frac{\partial t}{\partial\theta} = \alpha\left[\frac{\partial^2 t}{\partial r^2} + \frac{2}{r}\cdot\frac{\partial t}{\partial r} + \frac{1}{r^2}\frac{\partial}{\partial\mu}\left\{(1-\mu^2)\frac{\partial t}{\partial\mu}\right\} + \frac{1}{r^2(1-\mu^2)}\frac{\partial^2 t}{\partial\zeta^2}\right]$$

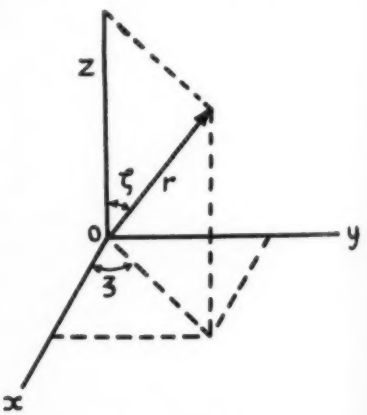


Fig. 4

The initial and boundary conditions considered are those of a hollow sphere, such that the two isothermal surfaces to be considered are concentric spheres, and the significant co-ordinates are the radius r and time θ. The equation then becomes

$$\frac{\partial t}{\partial \theta} = \alpha\left(\frac{\partial^2 t}{\partial r^2} + \frac{2}{r}\frac{\partial t}{\partial r}\right) \quad \ldots\ldots\ldots\ldots (29)$$

Thus, for conditions of steady temperature and uniform conductivity, the differential equation for the sphere is written

$$\frac{d^2t}{dr^2} + \frac{2}{r} \cdot \frac{dt}{dr} = 0 \quad \ldots\ldots\ldots\ldots\ldots (30)$$

and its general integral is

$$t = \frac{M}{r} + N \quad \ldots\ldots\ldots\ldots\ldots\ldots (31)$$

Let $t = t_1$ at $r = r_1$, where r_1 is the internal radius, and at the external radius r_2 let the temperature be t_2. These values are substituted as shown previously and, when M and N are eliminated, it is found that the temperature t for any point in the sphere is

$$t = \frac{r_2t_2 - r_1t_1}{r_2 - r_1} + \frac{r_1r_2(t_1 - t_2)}{r(r_2 - r_1)} \quad \ldots\ldots\ldots (32)$$

For a constant heat flux at the inner surface

$$f = -k\frac{dt}{dr} = \frac{k(t_1 - t_2)r_1r_2}{r^2(r_2 - r_1)}$$

so that the rate of heat flow/unit time is given by

$$q = 4\pi r^2 f = \frac{4\pi k(t_1 - t_2)r_1r_2}{r_2 - r_1} \quad \ldots\ldots\ldots\ldots (33)$$

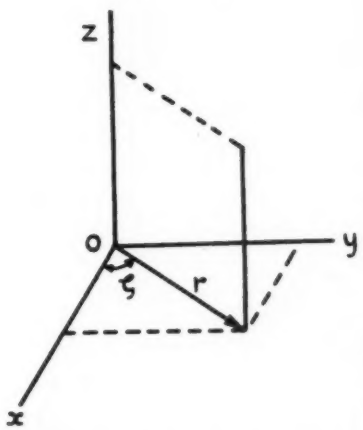


Fig. 5

In the case of the cylinder, the position of the point to be considered is determined by the polar co-ordinates r and ξ for its projection on the x—y plane, together with the co-ordinate z. This may be shown conveniently by Fig. 5, whilst the interested reader may turn to an excellent, detailed description of the calculation involved in reference 12. In this system it will be found that $x = r\cos\xi$, $y = r\sin\xi$ and $z = z$. The length of arc is given by

$$ds^2 = dr^2 + r^2d\xi^2 + dz^2$$

The procedure described earlier results in the general equation expressed in cylindrical co-ordinates, namely

$$\frac{1}{\alpha}\frac{\partial t}{\partial \theta} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial t}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 t}{\partial \xi^2} + \frac{\partial^2 t}{\partial z^2}$$

which may be written

$$\frac{\partial t}{\partial \theta} = \alpha\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r} + \frac{1}{r^2}\frac{\partial^2 t}{\partial \xi^2} + \frac{\partial^2 t}{\partial z^2}\right) \quad .. (34)$$

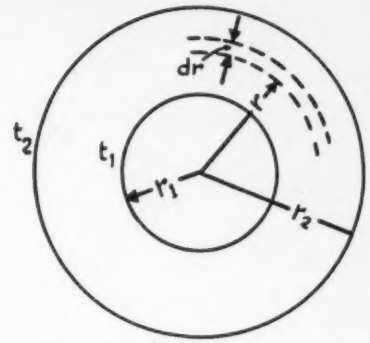


Fig. 6

Three interesting conditions may now be examined, of which probably the most important is the following case. If heat emanates from the axis z, so that the heat flow is radial, the initial and boundary conditions are independent of ξ and z, and thus t becomes a function of r and θ only. Thus equation (34) reduces to

$$\frac{\partial t}{\partial \theta} = \alpha\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r}\right) \quad \ldots\ldots\ldots\ldots (35)$$

It may be that z is not accounted for in the boundary conditions, in which case the heat emanation again is along planes which are perpendicular to the axis. The equation is then written

$$\frac{\partial t}{\partial \theta} = \alpha\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r} + \frac{1}{r^2}\frac{\partial^2 t}{\partial \xi^2}\right) \quad .... (36)$$

The important conditions where heat flow is along planes through the axis is that where the boundary conditions do not include ξ. The conduction equation then becomes

$$\frac{\partial t}{\partial \theta} = \alpha\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r} + \frac{\partial^2 t}{\partial z^2}\right) \quad \ldots\ldots\ldots (37)$$

Importance of insulation

Heat conduction through plane walls and surfaces, and the importance of heat insulation in these applications, is, perhaps, the most commonplace. There is no doubt that the hollow cylinder is the next most important consideration in modern chemical technology and insulation techniques. Fig. 6 shows the nature of the inquiry in relation to an infinitely long cylinder. The rate of heat flow for a cylinder of length L is given by

$$q = -kL.2\pi r\frac{dt}{dr} \quad \ldots\ldots\ldots\ldots\ldots (38)$$

When the conditions are those of steady temperature, and the flow is radial, equation (35) is written

$$\frac{d^2t}{dr^2} + \frac{1}{r}\frac{dt}{dr} = 0 \quad \ldots\ldots\ldots\ldots\ldots (39)$$

the general solution to which is of the form

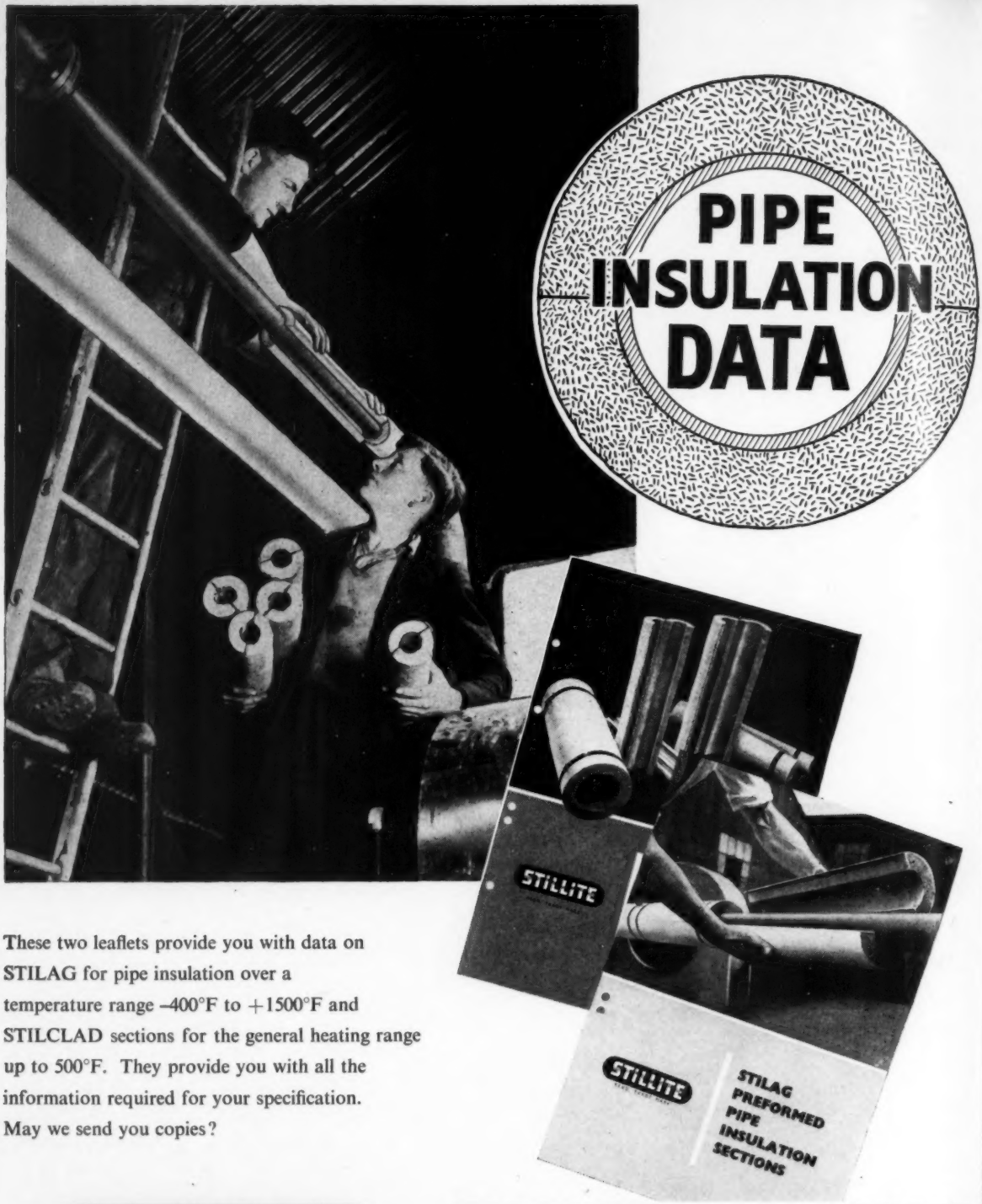
$$t = M\,ln\,r + N \quad \ldots\ldots\ldots\ldots\ldots (40)$$

The boundary conditions are obviously $t = t_1$ at $r = r_1$ and $t = t_2$ for the point $r = r_2$. These values are substituted into equation (40) to yield the constants as

$$M = \frac{t_1 - t_2}{ln\,r_1 - ln\,r_2} \qquad N = \frac{t_2\,ln\,r_1 - t_1\,ln\,r_2}{ln\,r_1 - ln\,r_2}$$

and, on appropriate substitution,

$$t = \frac{t_1 - t_2}{ln\,r_1 - ln\,r_2}\,ln\,r + \frac{t_2\,ln\,r_1 - t_1\,ln\,r_2}{ln\,r_1 - ln\,r_2} \quad .... (41)$$



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Chemical & Process Engineering

The rate of flow of heat for the length L is given by

$$q = \frac{2\pi k\ L\ (t_1 - t_2)}{ln\ r_2 - ln\ r_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (42)$$

giving a positive numerical value.

Mean area

Jacob[5] drew attention to the use of the mean area (A_m) for the cases of the cylinder and the sphere, which reduces the labour of calculation in many applications. The rate of heat flow for a cylinder, as discussed, may be written

$$q = \frac{1}{\varphi}\ k\ A_m\ \frac{t_1 - t_2}{r_2 - r_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (43)$$

which should be compared with equation (21).

The suggested mean area $A_m = L\pi(r_1 + r_2)$—the arithmetic mean area—and the quantity φ is a 'shape factor'.

On comparing equations (42) and (43) it will be observed that the value of φ is given by

$$\varphi_{cyl.} = \tfrac{1}{2}\ .\ \frac{(r_2/r_1) + 1}{(r_2/r_1) - 1}\ ln\ \frac{r_2}{r_1} \quad \ldots\ldots\ldots\ldots (44)$$

When the value of $(r_2/r_1) = 1.4$, $\varphi = 1.010$. That is, where

$$\left(\frac{r_2}{r_1}\right) \leqq 1.4$$

the radial flow of heat in the cylinder wall may be calculated as for a plane plate, if a maximum error of 1% can be tolerated.

In a similar manner this concept may be applied to the hollow sphere, and for this case

$$A_m = 4\pi\left(\frac{r_1 + r_2}{2}\right)^2$$

—the geometric mean area, which leads to the shape factor expression:

$$\varphi_{sph.} = \tfrac{1}{2} + \tfrac{1}{4}\ .\ \frac{r_1}{r_2} + \tfrac{1}{4}\ .\ \frac{r_2}{r_1} \quad \ldots\ldots (45)$$

An error of less than 1% in the same simplified calculation results when $(r_2/r_1) \leqq 1.2$, for at this value $\varphi = 1.008$.

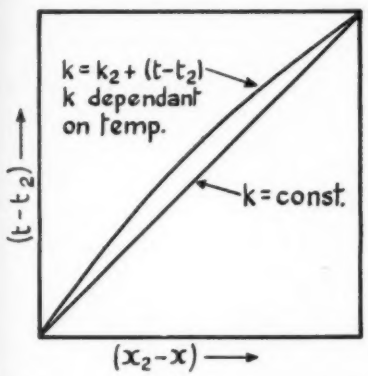

Fig. 7
Linear change of conductivity with temperature

The concept of a mean area had been examined by Langmuir, Adams and Meikle[14]—see also reference 13—in connection with rectangular bodies, such as a furnace or a refrigerator. It is evident, in these examples, that no simple area is satisfactory because of losses through the corners and edges. A well-known text[13] contains a full discussion on this subject, which includes a description of the experimental procedure used for the determination of

The second part of this article will appear in the October issue of CHEMICAL & PROCESS ENGINEERING

A_m in these examples. One only will be mentioned here to illustrate the method of use—a rectangular body having walls at least one-half as thick as the shortest dimension. The lengths y of all inside edges are between one-fifth and twice the thickness x of the walls. Let Σy represent the total of all the lengths of the inside edges. The actual inside area A_i is calculated and to the results is added $0.54\ x\Sigma y$ to correct for the edges; $0.15\ x^2$ corrects for each of the eight corners. In this way an expression for mean area is obtained, namely

$$A_m = A_i + 0.54\ x\Sigma y + 1.2\ x^2 \quad \ldots\ldots (46)$$

The value so obtained is then used in the calculation procedure for a plane wall.

Variation of thermal conductivity

Attention may now be drawn to the significance of the variation of thermal conductivity with temperature, especially in the common engineering example where k is a linear function of t. Thus if $k = k_2 + \beta(t - t_2)$ then $k_1 = k_2 + \beta(t_1 - t_2)$ and the mean value

$$k_m = \frac{k_1 + k_2}{2} = k_2 + \frac{\beta}{2}(t_1 - t_2) \quad \ldots\ldots (47)$$

For an infinitely wide plane plate

$$q = -\ kA\left(\frac{dt}{dx}\right)$$

so that appropriate substitution yields the expression

$$q = -\ [k_2 + \beta(t - t_2)]\ A\frac{dt}{dx} \quad \ldots\ldots\ldots (48)$$

Integration within the limits x_1 and x_2, and introducing k_m from equation (47), gives

$$q = k_m A\frac{t_1 - t_2}{x_2 - x_1} \quad \ldots\ldots\ldots\ldots\ldots (49)$$

where k_m is arithmetic mean.

Jacob[5] then shows that, if equation (48) is integrated within the limits x and x_2, there results

$$q\frac{x_2 - x}{A} = k_2(t - t_2) + \frac{\beta}{2}(t - t_2)^2$$

which may be solved algebraically to produce the expression

$$t = t_2 + \frac{k_2}{\beta}\left[\sqrt{1 + \frac{2}{(k_2)^2}\ q\ \frac{x_2 - x}{A}} - 1\right] \ldots (50)$$

in which a quadratic relation connects t and x. Equation (50) should be compared with equation (20), a linear relationship resulting from the assumption of constant k.

Fig. 7 serves to illustrate the significance of the foregoing discussion, and shows the temperature distribution for the conditions.

NOMENCLATURE

(Units commonly used are given in parentheses)

A = Area (sq.ft.)
E = Emissivity, in thermal radiation
M, N = Numerical constants
Q = Quantity of heat (B.Th.U.)
R = Thermal resistance

(*Concluded on page* 423)

Thermal Insulation

Some basic considerations

By J. W. Dawson*

IT is, presumably, because thermal insulating materials are, relatively, of low bulk density that a widespread fallacy has asserted itself; it is commonly supposed that the lightest materials are, *ipso facto*, the most efficient as thermal insulators—the lighter, so to speak, the better. The weakness of this supposition can easily be seen by considering, for example, a mass of fibrous insulating material. If individual fibres are, progressively, removed until only one or two remain, clearly these few fibres cannot have any appreciable influence on the flow of heat through the space originally occupied by the mass of fibres.

The truth of the matter is, of course, that the fibres themselves have, relatively, very little effect on resistance to the flow of heat; it is the air pockets or cells enclosed by the fibres which provide the great majority of the resistance. In order to establish what would be the ideal size and kind of cell or pore to produce the maximum resistance to heat flow, it is necessary to resort to elementary physics.

In any mass of air—or other gases—heat is transmitted by convection—that is, the movement of the air arising from its thermal expansion due to applied heat. The heated air, of course, expands, loses weight/unit volume and thereby becomes more buoyant; it rises above the cooler air which flows in to take its place. This progressive cycle produces a mixing effect which transmits the heat throughout the mass.

It has long been known, of course, that losses due to convection can be reduced by breaking up air spaces into smaller pockets and this is the principle of many kinds of insulating material. These materials are characterised by fairly large pores—easily discernible to the naked eye. To produce any further increase in resistance it is necessary to consider another mode of heat transmission—conduction among the ultimate particles or molecules. This, of course, involves the transfer of energy arising from collisions between molecules—for example in air at normal temperature and pressure—travelling at about 500 ft./sec. Under these conditions, the average distance between collisions—or the mean free path—is about 3.5×10^{-6} in. or 0.09 micron. Clearly in a space of 0.09 micron diam., inter-molecular collisions would be eliminated and, of course, heat loss by this medium would also be eliminated. The remaining difficulty—or the chief one—is the thickness of the dividing walls between the cells. If these are infinitely thin and enclose pores having a diameter equal to the mean free path for the particular gas, temperature and pressure involved, one will

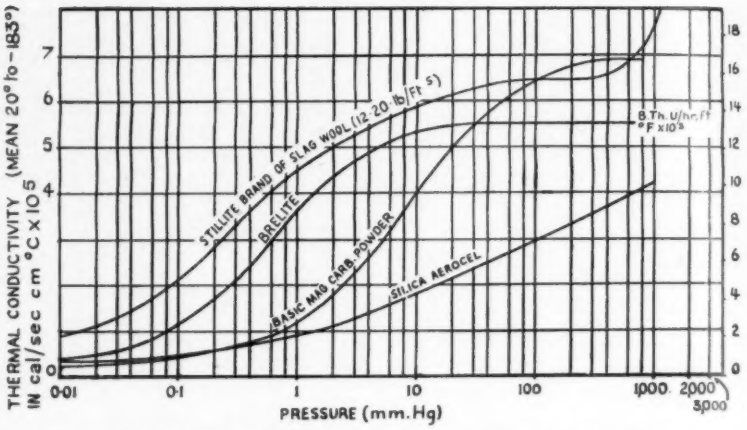

Fig. 1. Effect of pressure on thermal conductivity of insulants.

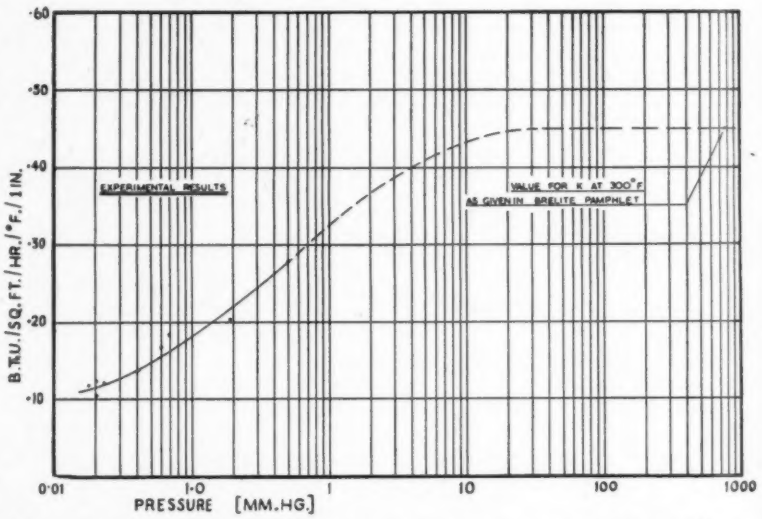

Fig. 2. Thermal conductivity of 'Brelite' at reduced pressure over range 260° to 370° F.

*Stillite Products Ltd., London

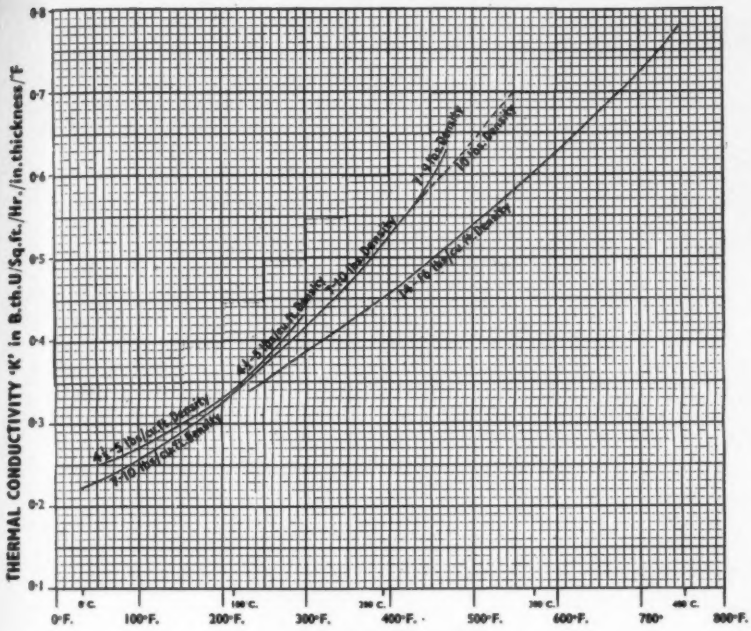

Fig. 3.

have almost reached perfection! A lustrous metallic surface would still further reduce the heat transmission by radiation from cell wall to cell wall.

Vacuum powder insulation

No known material closely approaches the standard described above, but it is interesting to note that a new technique known as vacuum powder insulation is being used on a commercial scale to exploit the principle involved. One of the materials used—perlite—is heat treated to produce a lightweight aggregate having remarkably small and evenly distributed pores. Silica aerogel (*Santocel*) has a similar structure with even smaller pores. In both these materials, the average pore is so small that, by evacuating the space in which they are housed, it is possible to increase the mean free path of the enclosed air so that it is approximately equal to the pore size. Fig. 1 shows the effect of a range of pressures from 760 to 0.01 mm. Hg on the thermal conductivity of four materials over the range of mean temperatures 20 to −183°C. It will be seen that for pressures of 0.01 mm. Hg there is a drastic reduction in thermal conductivity—in the case of *Brelite* (perlite) the reduction is 12-fold, from 0.15 to 0.012 B.Th.U./sq.ft./hr./1 in./1°F. etc. Mineral wool responds to this treatment provided the fibres are of a small enough diameter and packed closely enough to produce suitably small pores. The curve shown in Fig. 1 for *Stillite* corresponds to a density of 12 to 20 lb./cu.ft.

Fig. 2 shows the effect of reduced air pressure on *Brelite* over a range of temperatures—from 260 to 370°F.

Strictly speaking, apparent density can only be taken as a criterion of efficiency when comparing materials of similar structure. Perlite, for example, is a loose aggregate of ultra-lightweight particles and the density of the brand illustrated—*Brelite*—is 3 lb./cu.ft. *Stillite*, on the other hand, is an aggregation of very fine fibres—about 6 microns diam.—and the curve in Fig. 1 refers to a packing density of 18 to 20 lb./cu.ft. The respective porosities of the two products are: *Brelite* 98% and *Stillite* 89%. From this it will be clear that the degree of porosity is less important than the size and distribution of the pores.

To support this assertion, however, Fig. 3 shows the thermal conductivities of a wide range of densities of *Stillite* slabs for a range of mean temperatures from 0 to 750°F. All these densities are produced from identical fibre by varying the packing density and, thus, the size and distribution of pores. The densities, of course, extend from approximately 5 to 15 lb./cu.ft. and this corresponds to porosities from 97 to 91%—a total variation of only 6%.

Industrial Publications

Electrical instruments. Three publications have recently been issued by Negretti & Zambra Ltd. These are: R/30, dealing with electric switch and contact automatic controllers and alarm mechanisms; A/19, dealing with integrating indicator, type I.R., for use with the company's aircraft fuel flowmeter; and F25/S, the Spanish version of the company's general catalogue.

Corrosion resistance. Technical publication No. 20 concerning *Shieldcoat* and *Barriercoat* has been issued by Sealocrete Products Ltd. *Shieldcoat* is a gloss paint based on chlorinated rubber that will not saponify even when applied to alkaline surfaces, and is resistant to acid attack. *Barriercoat* is a corrosion-inhibiting primer based on calcium plumbate for application to metal surfaces before a final coating of a paint finish.

Radioactive chemicals and sources. Two catalogues for products available through the Radiochemical Centre have been issued by the U.K.A.E.A. The first deals with the primary isotopes and labelled compounds of interest to those who use radioactive tracer methods and with radioactive pharmaceuticals. The second deals with sealed radioactive sources and appliances which will be of interest to radiotherapists and to industrial users of ionising radiations. Both catalogues give the tariff for irradiation in the research reactors at Harwell. Most of the chemicals and sources in regular production are listed and users are recommended to choose these whenever possible on grounds of economy and ready availability.

Resins and glues. A revised edition of its catalogue of products, 'A Guide to Resins and Glues for Industry', has been produced by Leicester, Lovell & Co. Ltd. The catalogue is intended as a general guide to the company's range of synthetic resins (ureas, phenolics, resorcinols, epoxides and furanes), casein, PVA, animal glues and other adhesives.

Air conditioning and treatment. A booklet issued by Brightside Heating & Engineering Co. Ltd. has the theme the control of air, its movement, quantity and velocity, its moisture content, temperature and state of cleanliness, the factors which the air-treatment engineer has to consider when designing plant to cater for the needs of industry.

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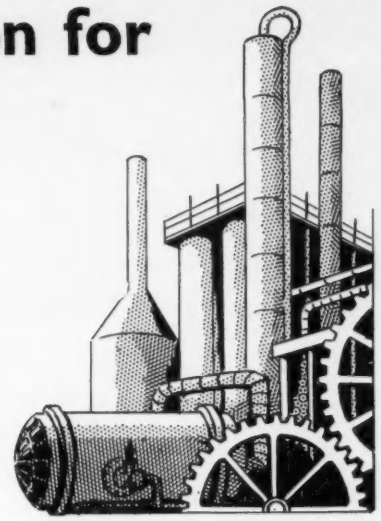
Materials of Construction for Chemical Plant



GRAPHITE

By K. F. Anderson,* B.Sc., F. K. Earp,* B.Sc., and S. Shapiro,* B.Sc., A.R.I.C.

This is the fifth article in our series 'Materials of Construction for Chemical Plant' which has so far included PVC, lead, nickel and stainless steel. Although carbon is the correct term describing mesomorphous carbon, natural graphite and electrographite, engineers commonly use the term graphite when specifying one member of the carbon family suitable for chemical plant. The physical properties of graphite differ markedly from metals and hence special design characteristics have to be taken into account. This article surveys the general applications of graphite in chemical plant—an increasing trend due to the extraordinary chemical properties of this material.

CARBON occurs naturally in the form of diamond, graphite and anthracite. Diamond is the purest form of carbon occurring naturally, graphite and anthracite being mined with varying amounts of impurity.

Graphite has been known for some considerable time, its earliest uses being confined to decorative purposes. It was thought originally that graphite contained lead and the names 'black lead' and 'plumbago' were applied to it.

Mixed with clay it has been used for the production of crucibles since the 16th century, but it was not until the 18th century that Scheele confirmed its true chemical nature by burning graphite in oxygen. A significant step forward in the uses of carbon took place when Sir Humphry Davy used electrodes cut from pieces of carbonised wood to produce an electric arc. Foucault furthered this application when he used rods sawn from lumps of retort carbon.

Carbon was first manufactured by methods similar to those used today in 1846 when Staite and Edwards patented the use of sugar as a binding agent for coke, which with subsequent baking 'cemented' the particles together. Later this process was used extensively for the manufacture of arc carbons and electrodes for furnaces. The manufacture of artificial graphite was begun in the late 19th century by a process developed by Acheson. He had previously found a method of producing silicon carbide by heating a mixture of sand and coke in an electric furnace to a temperature of 2,000°C. Upon increasing the temperature the silicon carbide decomposed, leaving a residue of graphite. Graphite anodes were first used by Acheson at the beginning of this century in electrolytic cells. They proved ideal for this application, due to their chemical inertness, high purity and low electrical resistivity. The rapid increase in the use of graphite for this purpose gave a considerable boost to the development of the carbon industry.

Carbon was first used in the metallurgical industry as a carbon hearth in a manganese furnace as long ago as 1865. In 1886 it was used in the hearth of a blast furnace and in 1892 in a calcium carbide furnace. Since 1930 an increased interest has been shown in the uses of synthetic carbon and electrographite, due to the first-class electrical, chemical and thermal properties possessed by such materials. One of the earlier uses was as tubes in a *Cottrell* precipitator handling phosphoric acid mist, where the carbon gave much improved life over ceramic tubes previously used. Other early uses of carbon as a structural material included the lining with carbon bricks of sulphite digestors used in the paper industries.

In 1936 and 1937 means of rendering carbon impervious were developed and this step greatly increased the use of carbon as a material of construction.

Outline of carbon manufacture

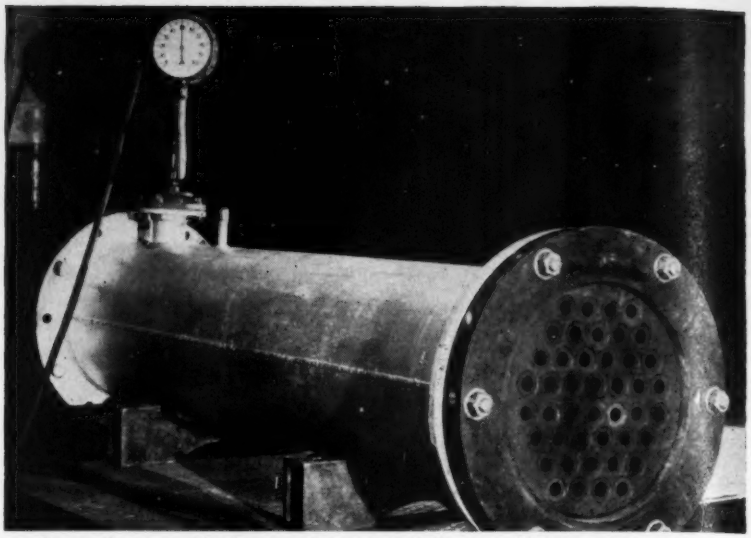
In the manufacture of carbon components it is possible to achieve a wide variation of physical properties. Such variation is produced by the selection of raw materials, and also by

*Morgan Crucible Co. Ltd.

adjustment of the many variables occurring in the stages of manufacture. Carbon is manufactured by blending together one or more types of coke, carbon black and graphite with a binder and then forming the required shape by moulding or extrusion processes. This is then subjected to high temperature in a reducing atmosphere to carbonise the binder and give permanence to the shaped article.

The raw materials which may be used include anthracite, retort cokes, petroleum cokes, charcoal, coke, carbon black, natural graphite and artificial graphite mixed with coal tar, pitch or synthetic resin. The various cokes used are produced by the distillation of coal during the manufacture of coal gas, whilst petroleum coke is the residue from the distillation of petroleum oils. Carbon black is made by the burning of hydrocarbon gases or oils in a restricted air supply, and charcoal by the firing of wood in an atmosphere from which oxygen has been excluded. The naturally occurring graphites may be in the form of flake or in a so-called amorphous form which are, in fact, finely crystalline.

During the first kilning cycle volatile matter is driven off from the shape, and the carbon particles are sintered together by the carbonisation of the binding material. In this form the shape is neither purely amorphous nor purely crystalline and can be best described as mesomorphous. Further heat treatment at a more elevated temperature can then be given to develop graphite crystal growth and form a synthetic graphite. This treatment is often carried out by employing the ware as a resistance heating element



Impervious graphite heat exchanger partially assembled for pressure test.

and the product is therefore normally called ' electrographite '. Upon the temperature and time of application of heat depends the ' degree of graphitisation ' and the degree of orientation of graphite crystals. In general, the crystal formation will be in planes parallel with the direction of extrusion, or perpendicular to the direction of pressing.

By selection of raw material and by variation of pressing force, time and temperature of the kilning and graphitising processes, a great variety of carbons, carbon/graphites, natural graphites and electrographites can be produced having physical properties best suited to their intended use.

In general the manufacturing process described above is used to produce material blanks which are further machined to produce the finished product. Carbon is relatively easy to machine by normal techniques to close tolerances. To reduce tool wear on machining abrasive carbons, it is desirable to use tools which are tipped with tungsten carbide.

Physical properties

From the foregoing it will be appreciated that only a range of approximate physical properties can be given for the various types of carbon. Such properties are given in Table I, which should be used in conjunction with the following definitions:

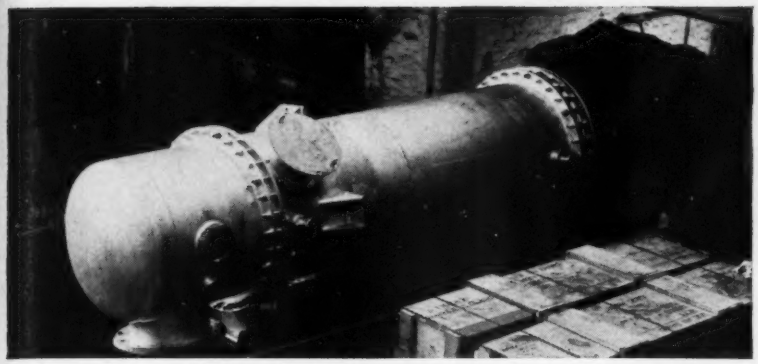
(*a*) Mesomorphous carbon is formed

Table I

Physical property		*Mesomorphous carbon*	*Carbon/graphite*	*Natural graphite*	*Electrographite*
Bulk density (lb./cu.ft.)		90 to 100	100 to 110	100 to 110	100 to 110
Hardness (° Shore)*		80 to 90	50 to 75	25 to 50	30 to 60
Porosity (%)†		10 to 30	10 to 30	10 to 30	10 to 30
Ultimate strength (p.s.i.):					
Tensile	Mean range	1,500 to 2,500	1,500 to 2,500	300 to 800	500 to 1,200
	Maximum	4,000	4,000	1,200	3,000
Shear	Mean range	3,000 to 4,000	3,000 to 4,000	1,000 to 1,500	1,000 to 2,000
	Maximum	6,000	6,000	2,500	3,000
Compressive	Mean range	10,000 to 12,000	10,000 to 12,000	2,000 to 3,000	4,000 to 6,000
	Maximum	26,000	26,000	5,000	12,000
Transverse	Mean range	3,000 to 6,000	3,000 to 6,000	2,000 to 3,000	1,000 to 2,000
	Maximum	10,000	10,000	7,000	4,000
Young's modulus (p.s.i.)		0.4 to 3.0 $\times 10^6$	0.4 to 3.0 $\times 10^6$	0.4 to 3.0 $\times 10^6$	0.4 to 3.0 $\times 10^6$
Coefficient of expansion (/°C.)		1 to 5 $\times 10^{-6}$	1 to 5 $\times 10^{-6}$	1 to 5 $\times 10^{-6}$	1 to 5 $\times 10^{-6}$
Specific heat (0 to 100°C.)		0.17 to 0.18	0.17 to 0.18	0.17 to 0.18	0.17 to 0.18
Resistivity (ohm. in.)		0.005 to 0.001	0.003 to 0.0009	0.001 to 0.0003	0.001 to 0.0003
Thermal conductivity (B.Th.U./hr.ft.°F.)		0.8 to 8.0	3.0 to 20.0	20 to 100	20 to 100

* The hardness figures are given for comparison purposes only. All carbon manufacturers use a Shore sclerometer in the assessment of hardness, but there is no guarantee that the missile is standard. Hardness figure should only be used for comparison between the products of a single supplier and not to compare products of different suppliers.

† The porosity range refers to the bulk of carbons used for mechanical and electrical purposes and does not include some of the ' porous ' carbons used for filtration purposes. It should also be appreciated that carbon and graphite are brittle materials and distinct from metals in that physical properties normally show a degree of scatter not associated with ductile materials.



Impervious graphite tube-in-shell heat exchanger—single effect evaporator.

carbon using coke or coal as a raw material not subjected to an ' electrographitising ' process.

(*b*) Carbon/graphite is a mesomorphous carbon using coke or coal plus additions of natural or synthetic graphite as a raw material.

(*c*) Natural graphite is formed carbon using natural graphite as a raw material not subjected to an ' electrographitising ' process.

(*d*) Electrographite is any of the above after subjection to an ' electrographitising ' process.

(*e*) Carbon is a general description of a formed component covering any of the above.

When considering carbon as a material of construction care should be taken to ensure that the best type of material is used for the particular application. Since carbon is a relatively new material of construction it is wise to discuss new problems with the manufacturer to ensure selection of the most suitable material.

Effect of temperature

In general, the physical strength of carbon is not adversely affected by temperatures up to 3,000°C. provided it is protected from oxidation; there is indeed some evidence that strength increases at very high temperatures. In oxygen the mesomorphous carbons and carbon/graphite will begin to oxidise at about 350°C., and natural and electrographites at about 450° to 500°C. with subsequent wastage and decrease in strength.

It should also be borne in mind that, should any of the carbon types be taken above their temperature of manufacture, further graphitisation will occur and the physical property trend will be towards that of electrographite. If the temperature of manufacture is not exceeded and the atmosphere is inert, the bulk density, porosity and coefficient of expansion will remain approximately constant. The coefficient of thermal conductivity of mesomorphous carbons and most carbon graphites increases with increase in temperature, whereas natural and electrographites normally suffer a decrease.

The electrical resistivity decreases with temperature up to about 1,400°C., though there is evidence that the resistivity/temperature relationship from 0° to 3,000°C. is parabolic for electrographites. Specific heats increase with increase in temperature.

Impervious and reduced porosity carbon

In the carbon manufacturing process volatiles are driven off from the pressed or extruded shapes during the heating cycles. The finished product is therefore porous in form. For many applications such porosity cannot be accepted and it is therefore necessary to carry out impregnation. Reduced porosity carbons fall into three main groups:

(*a*) Carbons which are impregnated with a material which can be converted to carbon by subsequent heat treatment. Very low permeability materials consisting almost entirely of carbon can now be produced by this method.

(*b*) Carbons which are impregnated with synthetic resins. Such impregnation is much used for carbons employed in the chemical plant field, since resins are now available which almost match the chemical resistance of carbon.

(*c*) Metal-filled carbons. Various metals can be successfully used to give additional strength and wear properties to carbon.

All types of impregnation serve to increase the strength and usually the hardness of carbon. By ' carbon ' and resin impregnation the ultimate physical strength can be increased by 1.5 to 2 times that of the basic grade, whereas a two- to three-fold increase can be gained by metallising. The effect of impregnation upon the coefficient of expansion, thermal conductivity and resistivity varies according to the type of impregnant and the nature of the base carbon. These effects can normally be estimated by considering two continuous phases, one of carbon and one of the impregnant.

Chemical resistance

Although the brittle nature of carbon is rather a drawback to its use as a material of construction, it is very strong in compression and it is widely used due to its excellent resistance to corrosive conditions. The only drawback to carbon is its readiness to combine with oxygen at high temperatures and under conditions of highly oxidising acid solutions.

Resistance to acids

Carbon is completely stable under most acid conditions up to the boiling point, although caution is advised when using carbon under the following conditions:

Nitric acid below 15% concentration at temperatures above 70°C.

Nitric acid of 15 to 30% concentration at temperatures above 50°C.

Nitric acid above 30% concentration at all temperatures.

Sulphuric acid above 70% concentration at boiling point.

Sulphuric acid above 80% concentration at temperatures above 80°C.

Sulphuric acid above 90% concentration at all temperatures.

Chrome-plating solutions of all concentrations at all temperatures.

Hydrofluoric acid above 60% concentration at all temperatures.

Phosphoric acid above 85% concentration at boiling point.

Phosphoric acid of 100% concentration above 80°C.

It should be noted that, whilst the chemical resistance of mesomorphous carbons and electrographites are similar in highly oxidising acid conditions, the hard mesomorphous carbons withstand attack better than natural graphite and electrographite. There is a tendency for carbon under oxidising acid conditions to swell, followed eventually by complete disintegration. This tendency is greater with the electrographites than with the mesomorphous carbons.

'Morganite' carbon segmental piston and bearing rings.

The performance of carbon in oxidising acid conditions can be improved by the use of certain impregnations. Such improvement, however, is possibly only gained by decreasing the surface area available for attack and restricting this to the surface. By careful selection of the impregnant, however, considerably increased life can be obtained.

Resistance to alkalis

As a general rule, carbon can be considered to be completely resistant to the common alkaline solutions at all concentrations and temperatures up to boiling point. It should be noted, however, that it is more difficult to obtain suitable impregnants to match this resistance, and therefore caution is advised when consideration is being given to impervious carbon.

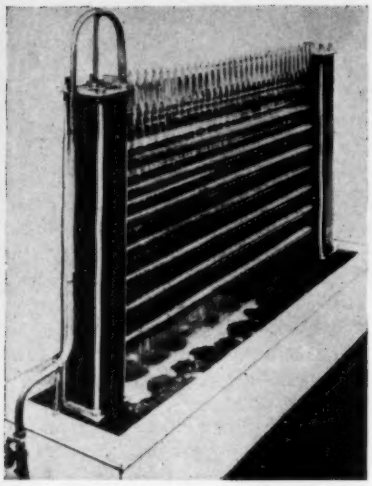
Resistance to other chemicals

Carbon has complete resistance to most inorganic and organic solutions up to their boiling points. Caution is recommended in the following cases:

(*a*) In the presence of sodium hypochlorite and hydrogen peroxide in all concentrations.

(*b*) In the presence of sulphur chloride and sulphur bromide.

It is likely that there are other complex solutions which will attack carbon, but these are rare. Attack on carbon can take place under the gaseous conditions of fluorine, bromine, iodine and chlorine dioxide. Other gases and vapours will not normally attack carbon at temperatures below the normal temperature of oxidation.



Impervious graphite cascade cooler.

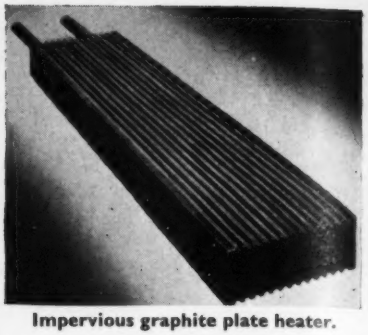
Heat exchangers

One plant application where carbon has been of considerable value is in the construction of heat exchangers. The performance and reliability of such units has been well proven and many heat-exchange systems requiring heavy maintenance have been replaced in the last decade with carbon heat exchangers.

An excellent example of such transformation is to be seen in the rayon industry, where the process involves the continuous heating of the spin liquor which is recirculated to the spinning machines. The rayon spin bath liquor, which is basically a 15% solution of sulphuric acid, was originally heated by lead coils immersed in the solution in large vats. This method of heating was inefficient and not easy to operate with continuous flow. The coil maintenance was heavy after a reasonably short operating period.

During the last ten years there has been almost a complete replacement of these rather outdated methods of heat transfer by graphite heat exchangers incorporated in the flow lines. Numerous impervious graphite heat exchangers are now used for heating, cooling, heat recovery and evaporation duties in the continuous process systems involved in rayon manufacture.

Similar transformation has also taken place in the closely allied transparent paper industry.



Impervious graphite plate heater.

The most recent phase of this operation has been the replacement of 30-ft.-high vertical callandria systems used on acid recovery by double-effect evaporator systems involving the use of tube bundle heat exchangers constructed from impervious graphite having an internal surface area of about 560 sq. ft.

The consideration of the designs of graphite heat exchanger affords an interesting study of carbon as a material of construction. The fabrication of plant in carbon poses two main problems:

(1) That of making impervious joints of carbon to carbon, since, unlike most other materials of construction, it is not possible to conveniently employ brazing or welding techniques.

(2) Carbon is a brittle material and low in tensile and shear strength; carbon must therefore be carefully handled and the design of fabricated components must take this fact into account.

Carbon is easy to extrude into tubular form and the first carbon heat exchangers took the form of the conventional tube-in-shell construction. In the initial construction of the tube bundle the problem of jointing electrographite tubes into carbon end plates was overcome by providing O rings between serrated tube ends and endplate recesses. The permanent solution to this problem, however, was in the use of specially developed resin cements having a filling of carbon or graphite. Cements are now available which almost match the chemical resistance of carbon itself, and which also have excellent adhesion to carbon. Cemented joints can therefore be made having complete impermeability to gas and liquid up to high pressures, provided that a pressure face is incorporated when making the joint.

Due to the lack of strength of carbon it is necessary to make tubes of rather more considerable wall thickness than is usual with metal tubes, the most

common tube size for the construction of graphite tube bundles being $1\frac{1}{4}$ in. outside diam., $\frac{7}{8}$ in. internal diam., and these can be incorporated with as small a triangular pitch as $1\frac{3}{8}$ in. Such tube-bundle construction cannot be claimed to be very robust and therefore careful handling is necessary when incorporating these units into their shells. Once incorporated in a mild-steel shell, however, these units are sufficiently robust to perform in a trouble-free manner under all heat-exchange conditions normally encountered. The general construction of carbon tube-bundle heat exchangers is the incorporation of the bundle into a mild-steel shell with suitably lined mild-steel end covers or carbon end covers when the corrosive condition is severe. In general, the corrosive is handled on the tube side of such units, but suitably lined shells can allow for corrosive conditions on both sides. Carbon shells are sometimes used for small units.

A further property of carbon which needs to be taken into account when it is used in conjunction with metals is its relatively low coefficient of thermal expansion. This factor necessitates the provision of a fixed head and a floating head in the design of a tube-bundle heat exchanger, the floating head being capable of taking up any differential expansions which may occur between bundle and shell and end covers. It is good practice to install such heat exchangers with the fixed head at a lower level than the floating head, so that the tubes remain in compression during operation. The conventional tube-bundle construction in graphite is popular and reliable and, if carefully installed and operated, needs little maintenance. Much of the maintenance required particularly in the replacement of broken tubes has been carried out in the past by the supplier. Many users, however, are now carrying out such maintenance using their own staff with complete success.

A number of novel forms of carbon heat exchanger have been designed which overcome the inherent lack of strength in carbon by providing a large mass with counter- or cross-flow passages incorporated in the mass. These units have the attraction that a large effective heat-transfer surface can be incorporated in a relatively small volume.

The first of these units takes the form of a cube of electrographite made up from a number of grooved plates bonded together with a carbon-loaded resin cement to give alternate flow passages at right-angles to one another. Suitable headers of steel or lined steel are tied to the faces of the cube to give cross-flow heat exchange.

Initially these cubic units were designed with flow passages rather too small in section and, under some conditions favouring scale formation, were prone to blockage. This possible fault has been recently rectified and the construction is therefore made rather more attractive.

A further type of massive block heat exchanger is designed to completely exclude cemented joints. This is attained by using rings of electrographite which are drilled both from outside to inside surfaces in a direction offset from the radial, and also parallel to the axis alternating with the passages through the wall of the rings. A series of such discs are assembled in compression with suitable gaskets between to build up the required heat-exchange area.

The ultimate in this type of construction is in very large, single blocks of electrographite drilled to give similar conditions to the cubic type without the disadvantage of cemented joints. Heat exchangers of this type are now available in the U.S.A. machined from large-diameter graphite rods, which are assembled into steel shells.

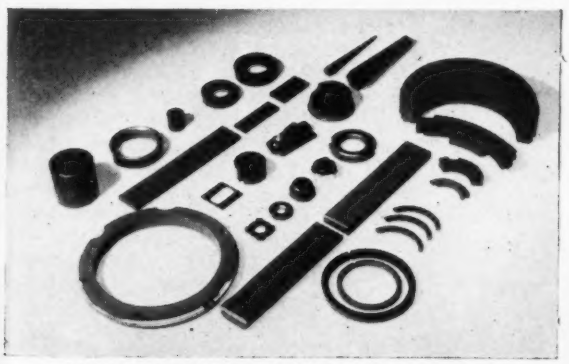
Brief mention should be made of two further circulation types of heat exchanger manufactured in carbon. These are the cascade cooler and the concentric tube heat exchanger, and both of these types can be efficiently employed for small duties.

Both types are constructed from graphite tubes bonded into end blocks of carbon. These ' elements ' are then piled vertically with the end blocks being tied together with suitable gaskets between to give the necessary heat-exchange area. In the case of the cascade cooler, water is cascaded down the banks of the tubes from an overhead weir-type distributor, whereas in the concentric tube unit counter-flow conditions are arranged in inner and outer tubes. In the concentric-tube type both tubes may be of carbon or the outer tube may be of any suitable material according to the chemical conditions.

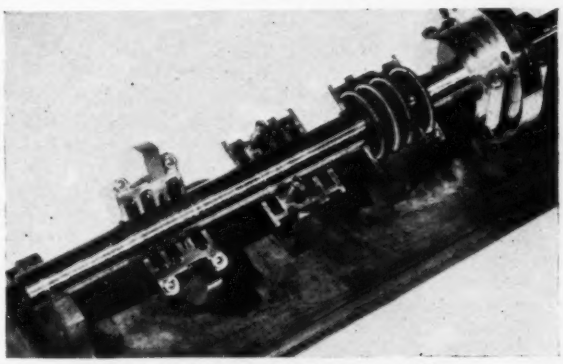
Comparison of different types

It is interesting to compare the possible advantages and disadvantages of the types of heat exchanger mentioned. Graphite has very high thermal conductivity and its non-wetting properties ensure unspoiled surfaces under most conditions. High overall coefficients of heat transfer can therefore be obtained by all types. Perhaps the inherently most efficient type is that of the composite rings, since interrupted flow passages are incorporated which ensure turbulent conditions. In this type of unit, however, the individual passages are small and under dirty conditions it is possible that regular cleaning is necessary to prevent blockage.

The tube-in-shell type is more bulky for given heat-exchanger surface than the block type, but it is possibly more trouble-free and more simple to maintain. Individual tubes can be replaced in a relatively simple manner should this become necessary. In the



Machined and fabricated carbon components.



Sectioned carbon gland ring assembly.

event of scaling of the tubes, however, it is not desirable to remove such scale by mechanical means, since tube breakage is a distinct possibility. From the maintenance point of view one of the possible disadvantages of the tube construction is that, should internal leaks develop between passages through the cemented joint, it must be rather an expensive matter to rectify such leakage. Cascade coolers and concentric-tube heat exchangers do not compare with the types previously mentioned as general-purpose heat exchangers. Cascade coolers are used for cooling duties only. They are quite efficient, inexpensive and easy to install and maintain, but have the disadvantage of not being totally enclosed. Concentric-tube units are capable of high performance for relatively small duties. For duties requiring large heat-exchange surface they are liable to become cumbersome.

Immersion-type heat exchangers

Immersion-type heat exchangers find their main outlet in applications where pumping is not desirable due to limited space for mounting external units, or where the corrosion problem is such that the suitable pumps are expensive or unobtainable. The coil system of immersion heating is impracticable with carbon and, although fabricated coils have been installed, they are not satisfactory for heating duties due to the great possibility of water hammer conditions being set up, particularly on start-up. The two main types of carbon immersion heater which are available take the form of the plate heater and the bayonet heater.

The plate heater is in the form of a solid block of electrographite which is machined with internal convolutions for the passage of steam or cooling water. The block is fitted with suitable risers for steam feed and condensate removal. This unit is quite robust and is to be preferred to the bayonet heater where there is danger of any mechanical impact.

Carbon bayonet heaters are constructed from an impervious electrographite tube which is threaded externally at one end, and internally at the other, to screw and bond a carbon flange and carbon plug respectively. The carbon heater flange is bolted to a steel flange carrying steam and condensate attachments, and a dip tube attached to the condensate line running nearly to the bottom of the tube. Steam is passed into the top of the tube, condenses and is forced by steam pressure up the dip pipe to a suitable trap. The bayonet heater can also be used for cooling purposes, in which case the dip pipe is normally centrally placed in the tube to give annular flow of cooling water. Of the two types of immersion heater the plate type is more robust and less subject to damage from water-hammer conditions. For equivalent surface areas, however, the bayonet is less expensive.

Live-steam injectors

Live-steam injectors are available in hard, erosion-resistant, impervious carbon and these are normally fabricated from square section blocks which are jointed together to give the required length. The assembly is fitted with a steam inlet port and a central steam passage. Dispersion of the steam is either by a series of outlet holes which are suitably disposed for either corner or side mounting, or by the incorporation of a nozzle in the main steam passage which sucks the liquor into the injector and disposes of it through an outlet near its base. The latter type gives most efficient mixing and stirring.

Carbon towers and packings

The construction of towers in carbon for absorption purposes is subject to limitation in size for single-piece construction. Although the maximum size of circular carbon rod production is always on the increase, the machining of the bore of such pieces is something of a problem and is still limited to about 24 in. diam. in lengths of about 9 ft. In general, therefore, carbon towers are constructed either by applying a carbon brick lining to mild steel or concrete, or by fabrication from impervious carbon blocks into a self-supporting structure. A further consideration of carbon linings is given below.

Conventional packings such as Raschig rings, Lessing rings, Berl saddles and bubble caps are available in carbon and there is also available a well-designed form of carbon grid packing fabricated from carbon slats.

Linings for chemical vessels

Carbon bricks and tiles are used quite extensively for lining chemical vessels and they give excellent resistance to corrosion and abrasion. Carbon bricks and tiles have been specially developed of a hard, durable, abrasion-resistant nature to resist the difficult conditions of agitated sediments and suspensions in corrosive liquids.

Due to the fact that carbon is porous, linings are normally provided with an impervious backing membrane of carbon-filled resin cement. Although it is possible to impregnate the bricks with resins to render them completely impervious, it is not easy to guarantee that joints which are completely free from pinholes can be obtained when installing the lining inside the vessel. The backing membrane is therefore normally considered necessary and can be of rubber, lead or plastic according to the chemical condition if preferred to the resin cement.

Resin cements have been developed to provide membranes either on steel or on brickwork or conventional cement. After the application of the membrane the carbon bricks or tiles are backed and jointed into position with a resin cement which has been specially developed as mortar.

As in many carbon fabrications, the cements play an important role in the construction of carbon linings and the available resin cements of the cashew, phenolic, furane and epoxy resins are adequate under most chemical conditions.

Small carbon components

There is a great demand for carbon for use as component items in pumps, compressors, valves and similar pieces of equipment. In most of these applications, carbon components are included where rubbing surfaces are involved and the low-friction and self-lubricating properties of carbon can be used to good advantage. The main uses are as follows.

(*a*) *Carbon sealing rings*, usually in resin-impregnated or metallised form, are used extensively in centrifugal pumps and other rotating mechanisms. Running against a counterface of cast iron, stainless steel or bronze of suitable hardness, carbon sealing rings give excellent life under arduous chemical and mechanical conditions.

The use of carbon sealing rings running against a counterface has a number of advantages over the conventional pump stuffing boxes. These include space saving, elimination of

The material of construction for chemical plant which will be discussed in next month's issue of CHEMICAL & PROCESS ENGINEERING will be

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shaft wear and the possible use at temperatures above those at which conventional stuffing box materials are suitable.

(*b*) *Carbon bearings* have found considerable application under conditions where it is necessary to avoid the use of conventional lubricants such as oil and grease. They can run satisfactorily without lubrication or alternatively in fluids which are not normally considered to have lubricating properties. Carbon does not seize on to metal, and carbon bearings have a considerable polishing effect on the shaft against which they rub, resulting in a great reduction in the rate of shaft wear. A further advantage of carbon bearings is that they can be used under high-temperature conditions where conventional lubricated ball or roller bearings cannot be used.

A typical high-temperature application includes bearings used on chain-grate stokers, flue-gas dampers, ovens and conveyors. Wet applications for carbon bearings include centrifugal pumps, fuel metering pumps, central heating circulating pumps, bottle cleansing plants, automatic washing machines and liquid measuring meters.

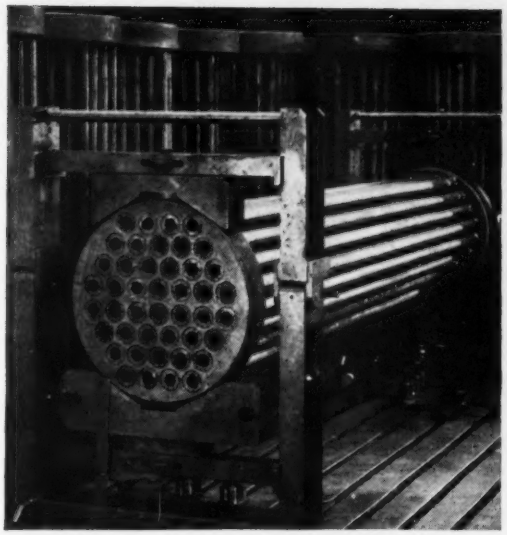
(*c*) *Carbon gland rings* are used extensively in steam turbines both as pressure seals in high-pressure glands and vacuum seals in low-pressure glands. They also find applications as air or gas seals in industrial plants, such as compressors, blowers and fans.

The use of carbon glands is an efficient method of sealing, since they can be mounted with smaller clearance than is possible with the metallic labyrinth alternative where metal-to-metal contact must be avoided. This also means that high-efficiency sealing can be obtained with a relatively short length of gland.

Due to the accuracy with which carbon can be machined, the larger gland rings can be made up of segments which can be butt jointed or tenon jointed. Carbon gland rings are also used extensively on water turbines.

(*d*) *Piston rings.* A further growing application for carbon is in the manufacture of piston rings for reciprocating air or gas compressors. Once again, the fact that lubrication is not necessary is a most desirable feature, since often the passage of lubricant from the compressor into the gas is undesirable or prohibitive.

In many industries the presence of oil in the compressed gases is dangerous and in others it is undesirable due to possible contamination of foodstuffs or staining of end products. Prior to the use of carbon, complex and expensive auxiliary plant was necessary to extract oil from the compressed gas after leaving the compressor, but with carbon piston rings this is no longer necessary.



Jig assembled impervious graphite tube-bundle.

It should be remembered that carbon piston rings, unlike standard metal rings, cannot be sprung into position over a piston and it is therefore necessary to employ a built-up piston, preferably of rust-resisting metal.

(*e*) *Vanes.* For the same reasons that carbon piston rings are useful for reciprocating compressors, carbon vanes find increasing application in rotary air compressors and vacuum and liquid pumps of the rotary type. Although it is essential that the vanes in carbon should be thicker than metal vanes they are very efficient in operation, ensure a low rate of cylinder wear and are capable of operation in dry or corrosive conditions.

Other applications include the all-carbon centrifugal pump which is so constructed that the corrosive liquid being pumped comes only into contact with carbon.

Other complete plant items include hydrochloric acid absorption systems manufactured completely in carbon, gas entrainment separators and carbon ejectors for lifting corrosive liquids from storage tanks. Carbon liners are used extensively for lining steam-operated air or gas ejectors; a complete range of carbon pipes and fittings is available, and carbon filters can be obtained in a wide range of size and porosity.

From the view of carbon applications mentioned in this article, it will be realised that by careful selection and design carbon can be used to great effect as a material of construction. It is almost certain that this material will become more extensively used in the future, as manufacturing and design techniques are improved for making the best of a material which offers such extraordinary chemical resistance.

Electronic safety system

A transistorised electronic brake for controlling the power of a nuclear chain reaction will be constructed for the U.S. Atomic Energy Commission's new Pathfinder Atomic Power Plant at Sioux Falls.

Engineers of the Bendix Corporation's Cincinnati division said the unit, called a reactor flux monitor and safety system, will automatically and continuously measure the number of neutrons or atomic energy output of the reactor from the start of its chain reaction through the full cycle of operations. Any time the energy output starts to exceed normal levels the system will automatically shut down the reactor in a fraction of a second.

Not only the amount of energy output, but also the rapidity with which it is being built up at any time, are sensed by this system, and if the reactor's human supervisors do not take indicated control methods when too-rapid build-up is taking place, the system automatically shuts it down.

Graphite for Heat Exchangers

By A. Hilliard*

The Polybloc *system for constructing chemical plant makes use of unit blocks of graphite with short passages. It is an interesting example of the necessity to design equipment around the unique properties of each material of construction, without reference to prior art. Thus this system results in improved mechanical and corrosion properties as well as utilising to the full the excellent thermal conductivity of graphite.*

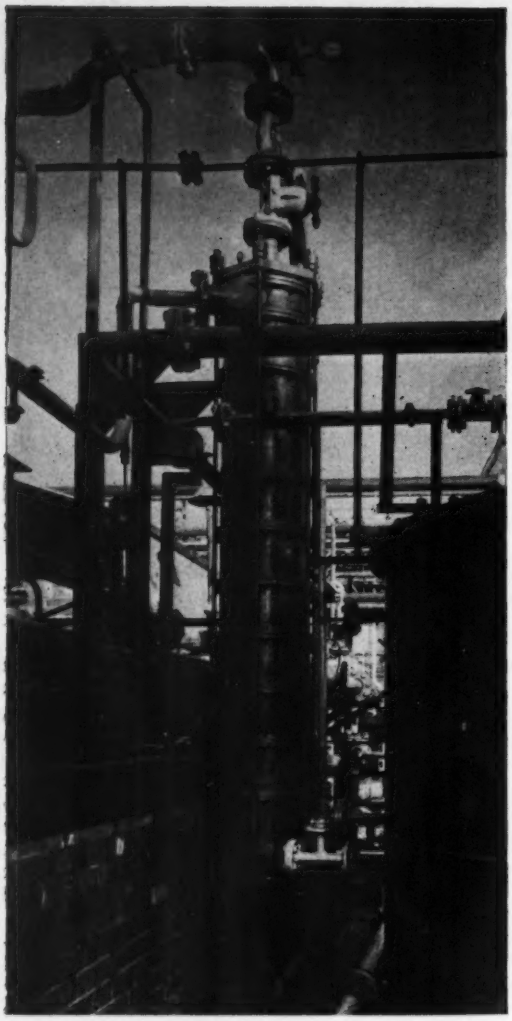


Fig. 1. ' Polybloc ' of 22 blocks for the cooling of sodium hypochlorite

THE vigorous expansion of the chemical industry in the past three decades created an increasing demand for equipment compatible with corrosive fluids. Graphite was an obvious choice because of its unique combination of excellent thermal conductivity with highly versatile corrosion resistance and easy machinability. Unlike the majority of constructional metals, graphite is highly anisotropic, is not malleable or ductile and cannot be cast or welded. Its most favourable mechanical property is its very good compressive strength.

A system of tubular construction had been developed over the centuries for heat exchangers made from metals which was well suited to the isotropic characteristics of these materials. The opposite was the case when the tubular system was applied to graphite constructions, because it failed to exploit the good compressive strength of graphite, subjected the graphite to tensile and flexural stresses and used the material in its more ' fragile ' form. Any preferred anisotropic crystal orientation is in graphite tubes opposite to the direction of desired heat transfer. Cemented joints are required to assemble the tubes in the header plates. These cemented joints, which have mechanical duties, are chemically and thermally less inert than is the graphite. Mainly because tubular graphite units are much more fragile than corresponding metal units, their use was generally limited to applications where no other convenient constructional material was compatible with the fluids to be treated.

To improve the robustness of graphite heat exchangers, monoblock types were developed, which were principally based on designs suggested initially by Stancliffe (between 1920 and 1930) for the manufacture of metal block heat exchangers by the lost core method of casting. Because of the difficulty of drilling long holes through solid graphite block, such monoblock units were assembled from plates, grooved on both sides and cemented together to form blocks with two sets of heat-exchange passages through them. Whereas they are more robust than graphite tube bundles, they involve a multiplicity of cemented joints, and they cannot use ' circular '

**Technical Adviser, Societe Le Carbone-Lorraine.*

header gaskets. Any preferred orientation of the long (conducting) graphite axes is at right-angles to the direction at which the plates are compressed, namely again parallel to the bore of both sets of heat-exchange passages.

Design factors

In view of these considerations, it is preferable to design equipment around the properties of graphite only, without any reference to prior art. The following principal factors bear upon the design of such ' new ' units:

(*a*) The use of compact blocks only, and the avoidance of any long, narrow shapes, such as tubes;
(*b*) The avoidance of any cemented joints.
(*c*) The maintenance of the unit exclusively under compression and the avoidance of tensile stresses.
(*d*) Any preferred orientation of graphite to be such that the long (conducting) crystal axes connect the two sets of heat-exchange passages.
(*e*) For easy fluid-tightness, the use of gaskets of circular shape only.
(*f*) The preference for equipment which can be built up from detachable standard unit elements.

A constructional method which satisfies these conditions is known as the *Polybloc* system.

The basic *Polybloc* element is a cylindrical graphite block with a central hole (Fig. 2). One set of heat-exchange passages (called axial) is parallel to the axis. The second set (radial passages) connect the central hole with the outer periphery of the block. Peripheral gasket grooves are provided at the two ends of the block. The space between the gasket grooves is slightly hollowed to produce ' turbulence chambers '. These blocks are assembled in a pile to obtain the required heat-exchange area (Fig. 3). Circular gaskets between the blocks ensure fluid tightness. Headers (*i.e.* distributors for the axial fluid) are provided at the two ends, and the assembly is held together, under compression only, by external spring-loaded tie rods. A detachable outer shell around the column of blocks contains the radial fluid. Multipass flow of the latter is obtained by the provision of baffles.

The process fluid may enter through the lower header at *C*, flow up through the axial passages of the lowest heat-exchange block into the first turbulence chamber, and continue its staggered flow through the assembly until it is discharged through the upper header at *D* (or *vice-versa*).

The service fluid may enter through orifice *A* at the upper end (left) of the outer shell, pass through the radial passages of the first block, into the central hole of the first and then the second block. There it is deflected by the central obstruction disc, and flows outwardly through the radial passages of the second block to the space between the column of blocks and the outer shell. It then flows down through that space until it is deflected by the obstruction ring into the radial holes of the third block inwards. It continues its sinuous flow through the heat exchanger until it is discharged through orifice *B* at the lower end (right) of the outer shell (or *vice-versa*).

Elasticity of movement of the column of blocks is allowed for by springs under the tie-bar nuts.

The outer shell sits by sliding joints on the column of graphite blocks to avoid any differential expansion stresses.

This system of construction, which is extremely simple, introduces the following principal advantages.

The compressive strength of graphite is fully exploited. Tensile or flexural stresses on the graphite are avoided, and the effective robustness is comparable with that of equipment made from metal.

Preferred orientation of the graphite crystals, with their long axes connecting the two sets of heat-exchange passages, produces thermal conductivity up to three times that of mild steel and up to ten times that of stainless steel.

The assembly is fully detachable, and the heat-exchange area can be easily increased on site (*e.g.* to meet increased production requirements) by adding a requisite number of blocks and shell elements.

The process fluid contacts only highly inert graphite and gaskets (the latter usually PTFE).

Technically, the most interesting aspect of the assembly is that it takes advantage of the end effect to inhibit streamline fluid flow. The small length-to-diameter ratio of the passages induces turbulent flow even at comparatively slow flow rates, and this explains the high heat-exchange efficiency of the system.

The turbulent flow inhibits scaling-up and fouling of the heat-exchange passages.

Because there are no cemented joints, the units are completely detachable, and best advantage is taken of the chemical inertness of graphite. The high heat-exchange coefficients and anti-fouling effects are obtained

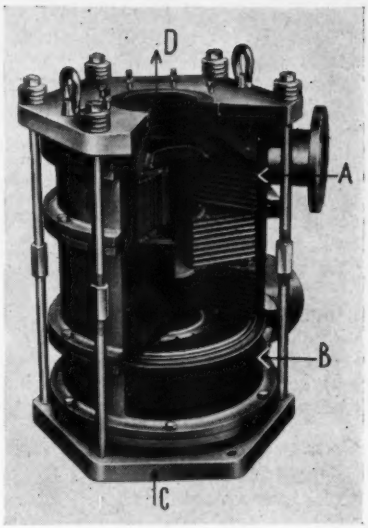


Fig. 3. Heat exchanger with part of the shell and blocks cut away.

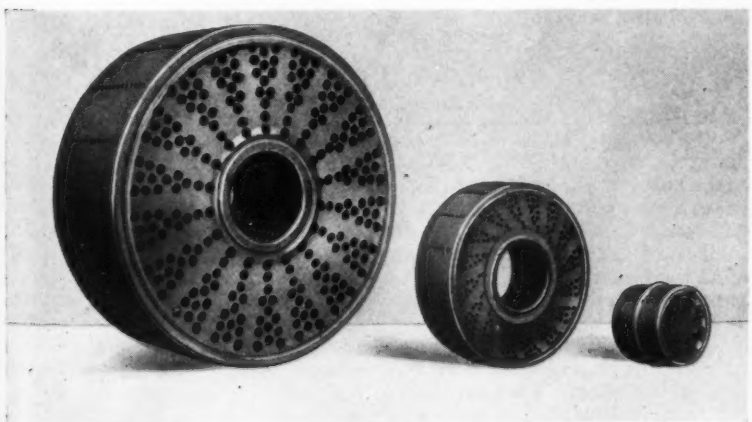


Fig. 2.

with a remarkably low pressure drop. The reason for this is obvious, because smaller heat-exchange areas are required for a given duty than would be necessary with a less efficient system.

Because of its versatility, the *Polybloc* system is applicable to the construction of practically all graphite equipment including heat exchangers, evaporators, condensers, concentrators, absorbers, scrubbers, strippers, etc. To meet each application to best advantage, minor modifications to the diameter and/or contour of the passages are all that are necessary. This will be illustrated by the following example.

Construction of absorbers

It will be seen from Fig. 4 that the radial passages are similar to those of a normal *Polybloc* heat exchanger. The

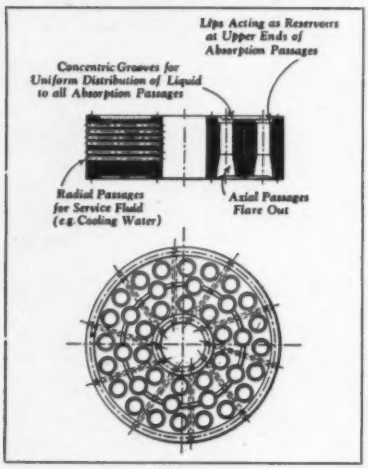

Lips Acting as Reservoirs at Upper Ends of Absorption Passages
Concentric Grooves for Uniform Distribution of Liquid to all Absorption Passages
Radial Passages for Service Fluid (e.g. Cooling Water)
Axial Passages Flare Out

Fig. 4.

axial passages are of larger diameter and flare out, trumpet fashion, towards the bottom in each block. The blocks are assembled in exactly the same way as those discussed earlier, using identical elements. The gas to be absorbed enters at the bottom of the apparatus and passes upwards through the axial passages. The continually changing shape of these passages induces turbulence of the gas (venturi effect), the molecules of which impinge on the descending film of liquid with greater violence than would be the case in straight tubes.

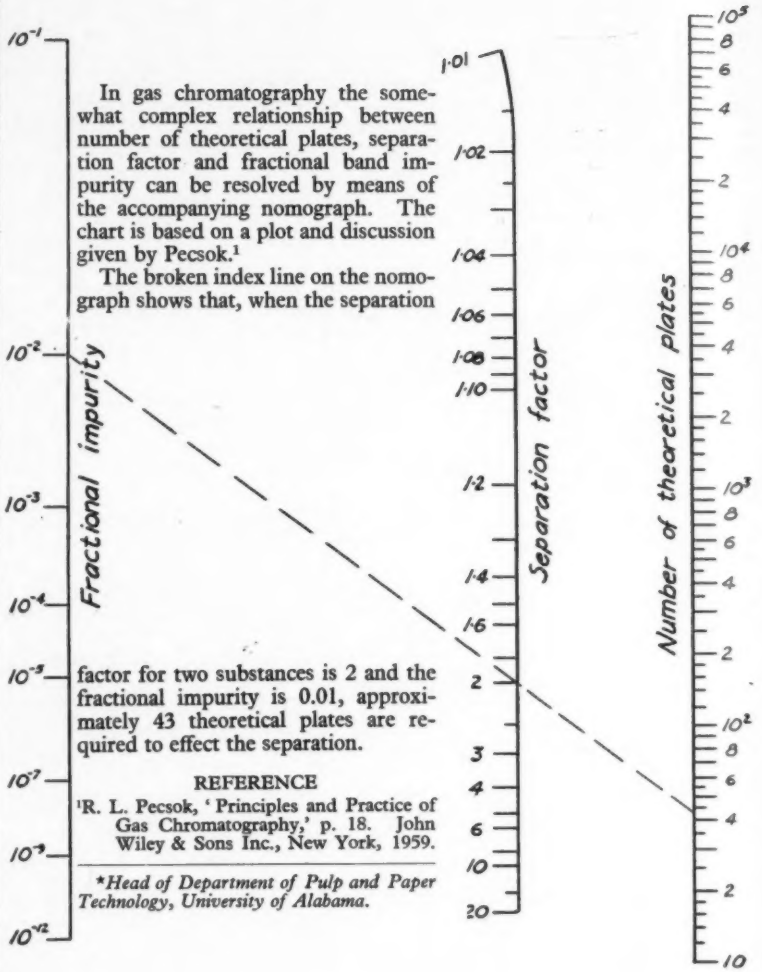
The absorbing liquid enters at the top of the assembly and collects in the hollow of the first turbulence chamber. A lip round the upper end of each axial hole ensures that the fluid runs as an even film down the walls of all the axial passages. The trumpet shape at the lower end of all axial passages causes the liquid to fall on to the hollow of the turbulence chamber at the upper end of the next block, and results in the liquid running as a uniform film down the axial passages of all the blocks. Concentric grooves at the upper end of each block ensure perfect distribution of liquid at every block interface (see Fig. 4).

Cooling or heating of the system is effected by passing a suitable heat-exchange medium through the radial system.

The arrangement per Fig. 3 can also be used for the concentration of a liquid. For example, if it is desired to concentrate sulphuric acid, steam or another convenient heating fluid can be passed through the radial passage system. In this case the dilute acid enters at the top of the assembly and descends as a uniform film downwards. The water, which is evaporated from the film, leaves through the top of the assembly and the concentrated acid is withdrawn from the lower end.

Nomogram for Gas Chromatography

By D. S. Davis*



In gas chromatography the somewhat complex relationship between number of theoretical plates, separation factor and fractional band impurity can be resolved by means of the accompanying nomograph. The chart is based on a plot and discussion given by Pecsok.[1]

The broken index line on the nomograph shows that, when the separation factor for two substances is 2 and the fractional impurity is 0.01, approximately 43 theoretical plates are required to effect the separation.

REFERENCE

[1]R. L. Pecsok, 'Principles and Practice of Gas Chromatography,' p. 18. John Wiley & Sons Inc., New York, 1959.

**Head of Department of Pulp and Paper Technology, University of Alabama.*

WHAT'S NEW

Plant • Equipment • Materials • Processes

CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.

Diaphragm valve

A split-body, single-seated diaphragm valve has been produced by Audley Engineering Co. Ltd. to supplement the range of Audco Annin *Domotor* valves for the simpler applications which do not justify the use of a positioner. Should a change of service justify the use of a positioner, it is possible to mount this on the top or side as desired. The valve body is produced in a variety of metals including cast iron, stainless steel and bronze, and is available in sizes up to 1 in. and will soon be available in sizes up to 2 in. **CPE 1551**

Thermal insulating material

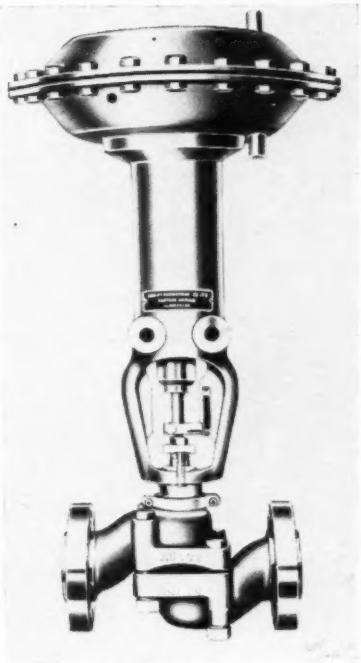
An improved type of magnesium carbonate insulating material is offered by the Chemical & Insulating Co. Ltd. This material, *Supermag*, is available in pre-formed sections and slabs for fitting to pipework and boilers for use in any industry where the prevention of heat is essential. It is a mixture of magnesium carbonate trihydrate with asbestos in the proportions 85: 15, as are the traditional magnesia compounds, but the manufacturing process changes its form and bonds it with the asbestos at a critical temperature.

It is said to be firmer, more easily handled, harder and stronger than orthodox magnesia products and is also resistant to water. It can be moulded to higher standards of precision. **CPE 1552**

Glass-fibre reinforced pipes

Flexo Plastic Industries Ltd. have recently acquired the British manufacturing rights for a patented method of fabricating glass-fibre reinforced polyester pipes and ductings.

This will enable the production of pipes with bore dimensions from $1\frac{1}{2}$ to 20 in., in lengths up to 40 ft. without joints. The wall thickness of the material can be varied between $\frac{1}{64}$ to $\frac{3}{16}$ in.



Diaphragm valve.

By variation of weaves of glass fabric, *i.e.* square weave, satin weave and unilateral weave, pipes can be designed to give major strength characteristics to suit specific applications. In addition, by incorporating synthetic fabrics of the *Terylene* type, chemical and abrasion resistance can be developed to meet severe corrosion problems.

The process will enable the production of flattened pipe which will have the same cross-sectional area as a normal pipe, but the resultant tube is flattened to give an oval cross-section. This could be important where space is at a premium. **CPE 1553**

Contamination monitor

Plessey Nucleonics Ltd. have recently delivered a consignment of food contamination monitors to the Ministry of Agriculture, Fisheries and Food.

These portable monitors are capable of detecting and assessing radioactive contamination present in liquid or solid foods due to fall-out from atomic devices. Rapid, radioactive assay can be carried out in laboratories, warehouses or in field conditions, simply and without skilled operators. **CPE 1554**

Curing at room temperature

Rubbers which can be cured at room temperature by the addition of one of two catalysts which are supplied with the product, and the curing time can be varied to suit the needs of the user, are offered by I.C.I. Ltd.

Silcoset rubbers are recommended for sealing, patching, caulking and potting applications where extremes of temperature are ultimately to be encountered and for moulding silicone rubber parts where curing is undesirable, or when the cost of conventional rubber moulding equipment is not justified.

When dissolved in a special solvent the rubbers can be used to coat an extensive range of organic and inorganic fabrics for use in electrical insulation and anti-stick applications. **CPE 1555**

Refining lubricating oil

When lubricating oil has been in use for some time it becomes contaminated with oxidised products and other impurities and loses its effectiveness as a lubricant. Passing through a centrifugal oil purifier is not adequate for complete purification, and refiners operating a full process are able to reconstitute and reblend lubricating oils to the specification of users' new

oil by a laboratory controlled process, so that waste is eliminated and effective lubrication is always ensured.

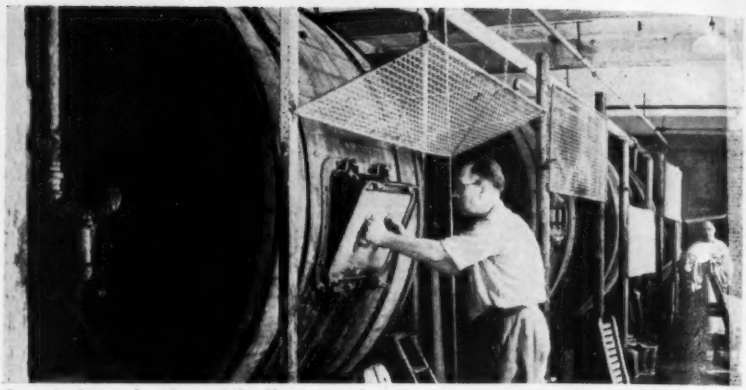
The first stage in the process involves removing all traces of moisture. The dehydrated oil is then sprayed with concentrated sulphuric acid, and the oxidised products are precipitated and run off from the reactor. The sour oil is then neutralised with alkali, treated with activated clay and finally filtered. If, as is often the case, the contaminated oil has lost its viscosity, new blending stocks are added, together with the necessary additives, to bring the oil up to its correct specification.

Midland Oil Refineries Ltd. offer their laboratory service free for the inspection and testing of contaminated oils for present and prospective users of the service in the re-refining of all types of contaminated oils, and typical of those they regularly treat are engine running-in oils, quenching oils, hydraulic and bearing oils, cutting and transformer oils. **CPE 1556**

Treated plywood

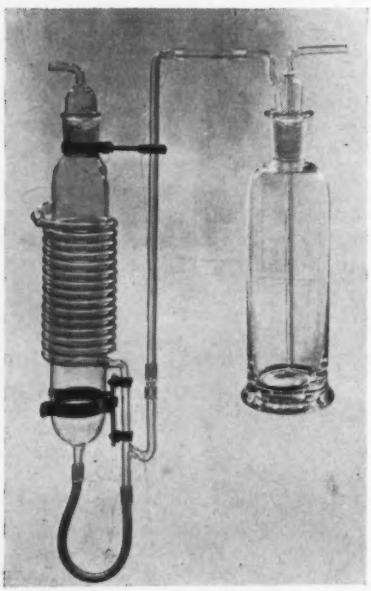
A chemically treated, waterproof plywood has solved a long-standing problem in the tanning plant of R. & A. Kohnstamm Ltd. Forming the access doors of large tanning drums, the plywood is said to be successfully resisting chromic acid, lime and chemical dye solutions that have made short work of ordinary timber and even solid metal.

The new doors are of *Permaply*, a resin-impregnated plywood made by Venesta Plywood Ltd. They are formed of *Permaply* sheet framed in gunmetal and secured by stainless-steel bolts; solid brass fixings originally tried corroded and soon became useless.



Access doors in these 8-ft.-diam. tanning drums are made of gunmetal-framed plywood.

The inner surface of the doors, inside the drums, is submerged almost continuously. Under this treatment, doors made from ordinary wood quickly began to swell, warp in their frames and finally split. The chemically treated plywood has remained flat and unbroken after nearly a year's exposure. **CPE 1557**



Apparatus for gas purification.

Gas purification system

An apparatus which gives a continuous stream of hydrogen, nitrogen, argon, etc., freed of the oxygen normally contaminating these gases as supplied in cylinders, is offered by Southern Instruments Ltd. Ordinary commercial nitrogen can be purified to a degree much superior to high purity commercial nitrogen and will reduce an oxygen content of 2,000 p.p.m. down to 0.2 p.p.m.

The apparatus consists of a pre-purifier containing an organic reagent which absorbs the major part of the oxygen. This reagent is then regenerated in contact with a bed of lead wool. The gas then passes to a scrubber which finishes off the purification. This scrubber is designed for highly efficient gas-liquid exchanges. The primary absorbent is a chromium salt which is oxidised, but reduced back by contact with amalgamated zinc.

The gas stream may flow at any rate up to 20 l./hr. and the reagents need only be renewed at long intervals. The two purifiers, which are mounted on a special stand, will also retain impurities such as CO_2, H_2S, SO_2, Cl_2, NH_3 and amines. **CPE 1558**

Detection monitor

A monitor for simultaneously detecting alpha and beta contamination on the hands and clothing of personnel working in nuclear reactor plants and similar establishments was shown in Soviet Russia for the first time on the stand of the manufacturers, E.M.I. Electronics Ltd., at the S.I.M.A. exhibition being held in the Polytechnical Museum, Moscow, last month.

By using a dual phosphor technique the monitor can check a person's hands for alpha and beta contamination in 5 sec. At the same time, two other persons' clothing can be checked.

CPE 1559

PNEUMATIC CYLINDERS

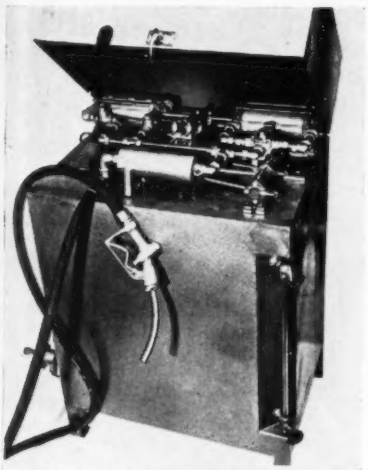
Martonair Ltd. offer a range of $\frac{3}{4}$-in.-diam. double-acting pneumatic cylinders. The cylinders are available in three stock lengths of stroke —1, 2 and 4 in. Construction is mainly non-ferrous and double-ended versions are available.

Each cylinder is fitted with a screwed nose and locknut for mounting, and is provided with two blind holes in the rear end cover for trunnion pins or the fitting of a rear hinge mounting. **CPE 1560**

Liquid detergent

A liquid detergent, *Amust*, is offered by Reddish Detergents Ltd. Supplied for general cleaning duties where one of the company's more specific products is not required, the detergent is claimed to be suitable for all industrial needs, including cleaning the interiors of motor vehicles, trains, buses, etc., and for canteen work.

It is available in 5-gal. and 40-gal. containers. **CPE 1561**



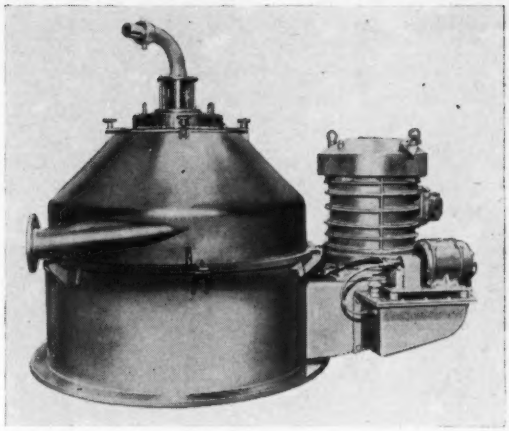
Liquid blending in diffuser chamber

Blending machine

A blending machine to suit a variety of industrial processes has been designed by Suba Hydraulics Ltd. to bring together two or more liquids and deliver in a pre-arranged proportion through a diffuser chamber just prior to delivery. It is claimed to eliminate the problems usually associated with pre-mixed blends such as setting out while in the storage vessel and intermediate tanks and pumps.

The original model was produced for Ford Motor Co. Ltd. for the rapid filling of radiators with a mixture of water and anti-freeze. It delivers 75% water, 25% anti-freeze, and by micro-adjustment of the cylinders a range of 84% water and 16% anti-freeze can be achieved.

All liquid-handling cylinders are in brass, end castings, pistons and valves are in bronze and the pipes and fittings are copper and galvanised steel. The tanks and cover are mild steel, all welded. The inside of the tank is treated with alcohol-resisting dressing and the outside of the tank and non-moving parts are finished hammer blue. The unit can be made in stainless steel wherever contact is being made with liquid being handled. **CPE 1562**



'Dynoscreen' continuous screen type centrifuge.

Screen-type centrifuge

The *Dynoscreen* continuous screen type centrifuge for the separation of solids from magmas and slurries can function either as a centrifuge or centrifugal screen. Fibrous and granular solids as well as powdery materials possessing free draining characteristics are said to be easily separated, and it is not essential for the specific gravity of the solids to be greater than that of the liquor in which they are suspended. When used to separate crystals from magma, the screen will deliver a product of uniform dryness into a drier at a continuous rate. Another application is the removal of the liquor occluded by plastics during polymerisation.

The makers are International Combustion Products Ltd. **CPE 1563**

Pre-coat filter

The *Funda* pre-coat filter is made by A. G. fur Chemie-Apparatebau of Switzerland and marketed in Britain by Mason & Morton Ltd. In this filter at the end of the filtration process the residue is flung off the surface of the filter elements by the centrifugal force produced by rotation and it is thus not necessary to open the filter at the end of the process.

The process is said to be equally applicable for clarification in which the filtrate is the final product, as for operation in which the residue or the cake is the ultimate object.

The process is fully automatic and continuous. Washing the wire screen of the filter cloth is also accomplished automatically with wash water or solvent through rotation of the filter elements.

The filter consists of a pressure vessel and a filter unit built of a number of circular filter elements attached to a vertical perforated rotatable shaft and separated from one another by distance pieces. Filtration takes place from the pressure vessel through the filter elements through the hollow shaft downwards. **CPE 1564**

Carbon disulphide production

A process which employs liquid petroleum fractions instead of conventional methane as in the production of carbon disulphide has been developed by Taylor Fibre Co., U.S.A., manufacturers of laminated plastics and vulcanised fibre. It is estimated that the liquid process will cost about 25% less in plant investment and 15% less in production costs than the methane process.

The greater flexibility in transporting liquid petroleum products is one of the advantages claimed for the process. Methane can be transported economically in large volume only through gas pipelines. Thus plant using methane must be either near methane producing centres or along pipelines, which rules out the use of methane in many countries. By contrast, liquid petroleum fractions can be transported by a variety of means—pipelines, sea-going tankers, tank cars and tank trucks.

The process produces a higher yield of carbon disulphide with less by-products and requires less handling and heating of sulphur per ton of carbon disulphide produced. Using heavy residuum, it produces more than twice as many moles of carbon dilsulphide/100 moles of reacted gases and hence recovery equipment and refrigeration requirements are much less than is required by the methane process. **CPE 1565**

New Books

U.S.S.R. Patents and Inventions. Vol. I, Nos. 1-2. Translation of journal *Biulleten' Izobretenii*. Pergamon Press Ltd., 1959. Appearing monthly. Annual subscription £50.

The spate of Russian technical literature at present translated into English seems to be increasing rapidly. This, of course, is one more proof that the English-speaking world is slowly grasping the unmistakable fact that the Soviet Union is in the forefront of technical and scientific developments, not only in sputnik production but also for more humble matter. Naturally, no country can afford to carry out industrial research and reap its fruits if it does not recognise the validity of patent rights. It is therefore pleasing to note that the application and granting of patents is now beginning to be taken as seriously in the Soviet Union as it is in the West. Pergamon Press have just published the first issue of the English translation of a selection of Russian patent abstracts. Altogether 17 categories of manufacture have been described covering chemistry, chemical engineering, mechanical and electrical engineering, agriculture, electronics, metallurgy, mining, measuring instruments, civil engineering, industrial gases, textile technology, building industry, fuels, food technology, public health, paper technology, precision engineering and aeronautics. Each category contains about 60 to 80 patent abstracts. It must be assumed, in fact, that this only represents a random selection of typical patents in these categories.

The section on chemistry and chemical engineering is very broad and covers all facets of the chemical industry. It would be next to impossible to review critically every patent mentioned in this section and therefore this reviewer can only make general comments on some trends in the Russian chemical industry. Most of the specifications indicate that there is very little difference between the Western and the Soviet chemical industry. Fluidised-bed catalysts, for instance, are being used in the oxidation of sulphurous anhydride. Terephthalic acid manufacture (the raw material for *Terylene*) warrants a special mention. An interesting specification describes corrosion-resisting linings based on metallic oxides; in order to confer ductility on the lining, metal resinates have been added to its composition. A vertical evaporating apparatus is described which has a separator for vapour-liquid emulsion and a conduit for return of the separated liquid into the evaporator. A rectification plant is described for alcohol mixtures in which contact between vapour and liquid is set up by atomising the liquid using the vapour, whereupon the mixture which has been formed is subjected to separation.

The publishers of this translation have indicated that the journal will appear monthly. It is very doubtful whether private subscribers could afford the very expensive annual subscription rate of £50. However, subscriptions to specialised sections are also accepted and they only cost a mere £15. Nevertheless, this journal should be of immense value to libraries and similar institutions. It is to be hoped that the time is not too distant when the Soviet Union will join the International Patent Convention and accept the privileges and obligations of this body. I.L.H.

3e Colloque de Metallurgie sur la Corrosion (Saclay, 1959). North-Holland Publishing Co., Amsterdam. Pp. 239. Illus. 70s.

Corrosion, gaseous and aqueous, was the topic at the Third Annual Metallurgy Colloquium, held under the auspices of the Centre d'études nucléaires de Saclay of the Commissariat a l'Energie Atomique from June 29 to July 1, 1959. The two previous symposia in this series were devoted to the ' recrystallisation of metals ' (1957) and ' diffusion in the solid state ' (1958). The texts of 20 papers covering various aspects of corrosion are published in the proceedings.

The papers presented cover a wide range of interests, which are not restricted to the nuclear energy field. In the opening paper of the colloquium J. Benard discusses ' the recent development of ideas on the oxidation of metals '. This paper is devoted largely to a review of recent results which throw light on the various stages of oxide film growth. In particular the phenomena of nucleation of oxide crystallites and surface diffusion during oxidation are examined. The role played by the various types of lattice defect during the diffusion of reactants through oxide films is considered by W. J. Moore (' Diffusion mechanisms and gaseous corrosion '). The relation between the diffusion coefficients measured using radioactive tracers and the diffusion coefficient obtained from the parabolic rate law constants is discussed and it is concluded that, within certain limits, the mobilities which govern the two processes are the same. J. Paidassi (' On the morphology of oxide films ') presents a wide range of micrographs grouped into six sections covering, respectively, the examination of precipitation in oxide films; the micrographic structure of oxide films; a study of the interfaces; the effect of the metal substrate on the growth of the film; nucleation of crystalline oxide particles in the film and their subsequent growth; and the plastic deformation of metals during oxidation.

Specific gaseous corrosion problems discussed at the colloquium are: ' The attack of graphite by gaseous impurities in a high-temperature, helium-cooled, graphite-moderated reactor ' (J. E. Antill and K. A. Peakall); ' The selection of alloys resistant to corrosion at high temperature ' (Mme. Genilloud); and ' The ignition of magnesium and uranium in air and carbon dioxide ' (R. Darras, P. Baque and D. Leclercq). In another paper Caillat, Darras and Leclercq make a novel suggestion for the inhibition of the corrosion of magnesium in moist air at high temperature by the addition of small quantities of hydrogen fluoride to the gas. The partially fluorinated oxide film produced under these conditions is more protective than the normal oxide.

A major part of the section dealing with aqueous corrosion is devoted to the various types of attack suffered by stainless steel. A general survey of the field is given by L. Colombier (' Certain factors in the corrosion of stainless steels in aqueous solutions '). Studies of the individual aspects of stainless-steel corrosion include 'A study of the precipitation of chromium carbide responsible for the intercrystalline corrosion of austenitic stainless steels ' (H. Hatwell); ' The corrosion by pure water at high temperature of stainless steels ' (E. Pouillard); ' Knife-edge corrosion of certain stainless-steel welds ' (J. Hochmann); and ' Precipitates, brittleness and intergranular corrosion of 18-8 stainless steel ' (J. Plateau, G. Henry and C. Crussard). The application of ' potentiostat ' techniques to the study of stainless-steel corrosion and the corrosion of aluminium-magnesium alloys

is discussed by Ph. Berge and P. A. Jacquet. Coriou, Grall, Le Gall and Vettier report evidence of the susceptibility of *Inconel* to stress-corrosion cracking in high-temperature water; this is the first occasion on which this type of attack on *Inconel* has been demonstrated.

Other topics discussed in the aqueous corrosion section are sea-water corrosion (' The IRSID sea-water corrosion testing station — principal results obtained at Biarritz ', by A. Hache). A study of the influence of hydrogen on the corrosion of zirconium and its alloys in high-temperature water (J. N. Wanklyn) illustrates the use of capacitance measurements, combined with weight change data, as a measure of the protective character of oxide films. Oxides produced in air, steam and during cathodic polarisation in water are compared by this technique. Finally two papers are presented on corrosion under the influence of sulphur: ' The fixation of radioactive sulphur on the surface of iron and its influence on electrochemical corrosion (B. Le Boucher, C. Libanati and P. Lacombe) and the ' Present state of our knowledge on the corrosion of steels by hydrogen sulphide ' (E. Herzog). B. Cox

Ionisation Phenomena in Gases. By Gordon Francis. Butterworth. Pp. 300. 60s.

No student of science these days can afford to be ignorant of the phenomena of gaseous ionisation, which finds application in so many measurements, processes and types of equipment in industry and the research laboratory. Spraying of highly refractive materials (metallisation), discharge lamps, vacuum gauges, electronics, radio transmission, welding torches, radiation counters and power from nuclear fusion are all possible fields of application, to mention but a very few.

This book is an excellent introduction to a tremendously important science. Its introductory section deals with spectra and wave mechanics, electrical conduction in gases, types of collisions between particles, excitation, thermionic emission, the statistical characteristics of energy distribution and de-ionisation. Then comes a mathematical treatment of the similarity laws, the uses of which are given. A chapter on alternating and high-frequency discharges includes details of some of the experimental methods and interpretation of the results. Particularly fascinating is a section on ionisation and excitation in the upper atmosphere, including the aurora. It is a pity that more could not have been included on the nature of the radiation belts which have been detected by artificial satellites and rockets about 500 km. above the earth's surface.

Chapter 6 deals with high-current discharge and thermonuclear effects, including the now-famous ' pinch effect '. The importance of these phenomena for power production is stressed, as are the criteria for a reactor based on this concept. Joule heating, magnetic compression, acceleration and beam mixing, toroidal pinch, stellarators and mirror machines are all described. Theories of plasma oscillations and waves are covered in Chapter 7, as are the motions of electrons and ions in magnetic fields.

This volume is a first-class account of a very important field of work, carefully prepared and well presented. It is illustrated adequately and the type is excellent. Errors must be very few, for I failed to find any on the first reading. I can recommend this book to every student of physics, and indeed to many engineers as well, at degree level. F. R. PAULSEN

Thermal Conduction and its Special Application to Thermal Insulation

(*Concluded from page* 405)

NOMENCLATURE—continued

T	= Absolute temperature (°R = °F., *i.e.* °F., absolute)	β	= Constant in thermal conductivity equation
$[L]$, $[M]$, $[T]$	= Dimensions of mass, length and time, respectively	ξ	= Angle (latitude)
c	= Specific heat (B.Th.U./lb. °F.) (c_p, specific heat at constant pressure, may be used)	ζ	= Angle (azimuth)
		θ	= Time
f	= Heat flux	λ, μ, ν	= Direction cosines
$\boldsymbol{f}$	= Flux vector	ρ	= Density
h	= Film coefficient of heat transfer {B.Th.U./(sq.ft.)(hr.)(°F.)}	φ	= Angle; shape factor; (function)
		ψ	= Function
k	= Thermal conductivity {B.Th.U./(sq.ft.)(hr.)(°F./ft.)}	Δ	= Area; difference
		Subscripts:	
l	= Typical dimension (ft.)	i	= Initial conditions
q	= Rate of heat transfer {B.Th.U./(sq.ft.)(hr.)}	s	= Relating to surface
r	= Radius	e	= Relating to environment
t	= Temperature (°F.)	r	= Implying radiation
u	= Function	c	= Implying convection
x	= Distance (ft.)	t	= A total value
α	= Thermal diffusivity (sq.ft./hr.)		

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CPE Diary

SEPTEMBER 20 TO 23 **Course for directors and senior executives in industry** organised by the U.K.A.E.A. at Wantage. Information from U.K.A.E.A. Isotope School, Wantage Radiation Laboratories, Wantage.

SEPTEMBER 21 TO OCTOBER 1 **International Factory Equipment Exhibition** at Belle Vue, Manchester. Information from the organisers, Industrial & Trade Fairs Ltd., Drury House, Russell Street, Drury Lane, London, W.C.2.

SEPTEMBER 22 AND 23 Symposium on **the manufacture and use of some catalysts in the petroleum and petrochemical industries** at the Donnon Laboratories, Grove Street, Liverpool. Organised by the Liverpool section and Chemical Engineering Group of the Society of Chemical Industry. Details from Mr. J. H. Jarwood, Peter Spence & Sons Ltd., Widnes, Lancs.

SEPTEMBER 22 AND 23 Symposium on **the protection of gas plant and equipment from corrosion** at the College of Advanced Technology, Birmingham. Organised jointly by the college, the Institution of Gas Engineers and the Society of Chemical Industry, Corrosion Group. Details from department of chemistry of the college, Suffolk Street, Birmingham 1.

SEPTEMBER 22 TO 24 Conference on **the theory and practice of ultrasonic inspection** to be held at the Queens Hotel, Cheltenham. Organised jointly by the Institute of Physics' Non-Destructive Testing Group, the Society of Non-Destructive Examination and the Non-Destructive Testing Society of Great Britain. Details from the conference secretary, I. M. Barnes, Materials Laboratory, de Havilland Propellers Ltd., Hatfield, Herts.

SEPTEMBER 26 TO 28 Summer school on **the protection of metals by paints** to be held at Battersea College of Technology. Details from the summer school secretary, Battersea College of Technology, London, S.W.11.

SEPTEMBER 27 TO 28 Symposium on **automatic control** sponsored by the British Conference on Automation and Computation and arranged by the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

SEPTEMBER 29 TO 30 Symposium on **powders in industry:** properties and principles of application, to be held at the Royal Institute, London. Organised by the Surface-activity Group of the Society of Chemical Industry, 14 Belgrave Square, London, S.W.1.

SEPTEMBER 29 Robert Horne Memorial Lecture to be delivered by Prof. F. D. Richardson in Bristol. Title: **The Extractions of Metals and the Chemistry of Melts.** Organised by the Society of Chemical Industry, 14 Belgrave Square, London, S.W.1.

OCTOBER 3 TO 7 **Brewers' and Allied Trades'** Exhibition at Olympia. Details from the organisers, Trades, Markets & Exhibitions Ltd., Grand Buildings, Trafalgar Square, London, W.C.2.

OCTOBER 4 TO 7 Conference on **synthetic rubber and synthetic fibres for the rubber industry** at the Berlin Congress Hall. Details from the organisers, Deutsche Kautschuk-Gesellschaft der Bunawerke Huls GmbH., M. Marl, Kreis Recklinghausen, Western Germany.

OCTOBER 7 Castner Memorial Lecture will be delivered in Glasgow by Dr. W. J. Kroll on the **Fusion Electrolysis of Titanium.** Organised by the Society for Chemical Industry, 14 Belgrave Square, London, S.W.1.

OCTOBER 11 TO 14 Symposium on **inelastic scattering of neutrons in solids and liquids,** to be held in Vienna. Details from the organisers, I.A.E.A., 11 Kartner Ring, Vienna 1, Austria.

OCTOBER 18 TO 21 **Effluent and Water Treatment** Exhibition and Convention at the Symour Hall, London, W.1. Details from the organisers, Thunderbird Enterprises Ltd., 140 Cromwell Road, London, S.W.7.

OCTOBER 23 TO 30 Thirty-second **Congres International de Chimie Industrielle** in Barcelona. Details from the organisers, Chimie et Industrie, Soprodoc, 28 Rue Saint-Dominique, Paris 7.

OCTOBER 24 TO 27 Symposium on **chemical effects of nuclear transformations** in Prague. Organised by International Atomic Energy Agency, Vienna.

OCTOBER 29 TO NOVEMBER 7 Standard course on **reactor technique** at the Harwell School. Details from the principal, Reactor School, A.E.R.E., Harwell, Didcot, Berks.

NOVEMBER 1 AND 3 The autumn meeting of the Institute of Welding to be held in London and will be devoted to the **metallurgy of welding and brazing.**

NOVEMBER 8 TO 10 Conference on **non-destructive testing in electrical engineering.** Details from the organisers, the Institution of Electrical Engineers, Savoy Place, London, W.C.2.

NOVEMBER 28 TO DECEMBER 2 Symposium on **experimental and test reactors** in Vienna. Information from the organisers, I.A.E.A., 11 Kartner Ring, Vienna 1, Austria.

NOVEMBER 29 TO DECEMBER 2 **The Corrosion and Metal Finishing Exhibition** to be held at Olympia. Organised by Leonard Hill Ltd. Details from the Director, the Corrosion and Metal Finishing Exhibition, 9 Eden Street, London, N.W.1.

NOVEMBER 30 TO DECEMBER 2 Symposium on **steels for nuclear reactor power circuits** at Church House, London, S.W.1. Details from the Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

NOVEMBER 30 TO DECEMBER 2 Second **Reinforced Plastics** Conference at the Cafe Royal, London. Information from the British Plastics Federation, 47-48 Piccadilly, London, W.1.

DECEMBER 15 TO 16 Meeting of the **Powder Metallurgy** Joint Group of the Iron and Steel Institute to be held at Church House, Great Smith Street, London, S.W.1. Details from the group secretary, 17 Belgrave Square, London, S.W.1.

Three Centuries of Science

NEVER has the Royal Albert Hall provided a more appropriate setting for the Academic Festival Overture, if only because the occasion that Brahms' music was embellishing was perhaps the greatest academic festival of the century—the tercentenary of the Royal Society. By 2.45 on Tuesday afternoon, July 19, the arena of the Albert Hall was filled with a vast crowd, assembled to witness the ushering in by the Queen of the fourth century of Britain's national academy of science.

The bandsmen and trumpeters of the Royal Military School of Music played Handel, Bach and Brahms as the glittering procession entered the hall, moving slowly down the main aisle to the stage usually occupied by the world's great orchestras. First came the Fellows of the Royal Society, in academic robes.

Then came the foreign members of the Royal Society and official representatives of national academies of science, universities and international scientific organisations.

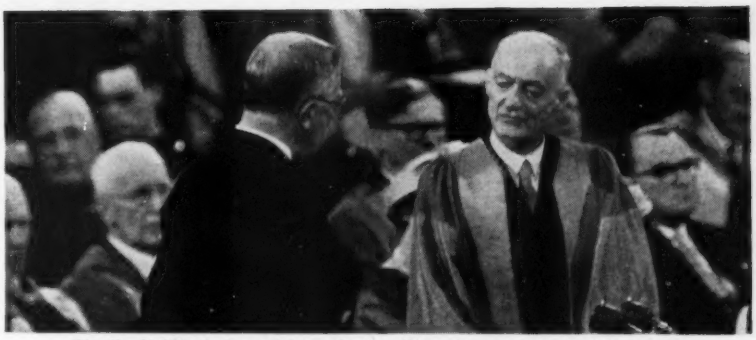
Then came the council and past-officers of the Royal Society (including three ex-presidents, Dale, Robinson and Adrian) preceded by the famous mace of the Society.

Finally came the Queen, the Duke of Edinburgh, the King and Queen of Sweden and the P.R.S., Sir Cyril Hinshelwood, Professor of Chemistry at Oxford. The Queen wore a flowered hat and a lime-green dress; the Duke was in morning dress. After the National Anthem the Queen spoke.

She recalled the founding of the Society under the patronage of Charles II and referred to some of the great Fellows—Newton, Darwin, Watt, Kelvin and Parsons. The Society ordered its affairs today in much the same way as it always had, said the Queen, but an innovation that gave her special pleasure was the admission of women to the Fellowship. After welcoming the foreign visitors she presented the Society with a silver bell to mark her continued interest as patron and to ring in the fourth century of the Society's history.

Sir Cyril Hinshelwood thanked the Queen and then Sir Arthur Bliss, Master of the Queen's Musick, conducted his own work, ' Salute to the Royal Society on the Occasion of its Tercentenary '.

The pageantry continued with three representative addresses of congratulation given by Prof. Graffi, representing the University of Bologna, Prof. Lecomte representing the Academy of Sciences of France, and Sir John Eccles, president of the Australian Academy of Science.



Sir Cyril Hinshelwood introducing King Gustav Adolf of Sweden.

After the president had expressed his thanks for what he called ' these precious manifestations of goodwill ', he formally introduced King Gustav Adolf VI of Sweden for admission to the Fellowship. The King signed the charter book and then, in flawless English, addressed the assembly. He referred to Linnaeus, his own compatriot, who was a Fellow, and then to the many Fellows, including the president, who had received Nobel prizes. The Royal Society, he said, had served as a model for most other national academies of science, not least the Royal Swedish Academy, founded in the 18th century.

For 40 min. Sir Cyril laid what he called an account of the Society's stewardship before the world. In achievement the 300 years of its existence had exceeded all the infinite wastes of evolutionary time; ' by the scale of human events they are the fullest and longest in existence '.

The men who founded the Society were still fresh in mind and their dedication to the uncovering of the secrets of nature had established a living tradition. Much was said of the sympathy with which the Society's establishment was received, but the founders met fierce criticism and even in 1700 the corporate income of the Society was no more than £100. But the original Fellows lived up to the Society's motto *Nullius in Verba*, accepted none of the authority of dogma and remained unmoved by praise or blame.

They were a minority and so was the Society of today—a specialised minor community large enough to command prestige and confidence but with membership confined to those who placed the claims of knowledge first. The principles which should govern such a body were highly important, said Sir Cyril. 'An academy is the natural body to provide several vital things, non-commercial periodicals for the publication of discoveries . . . financial support for ideas still too embryonic to be of immediately obvious practical application, the mutual stimulus of association and discussion and the immaterial reward of honour for intellectual achievement '.

The Society was no rival to government organisations or to industry and it maintained the closest connections with them by electing into its numbers leaders of both. So it exerted influence far beyond the confines of the learned world.

The president ended his broad and beautifully composed survey with a look at the future. The task of scientists was clear; it was to go ahead undeterred by uncertainties. ' Not exemption from danger, hostility or temptation but the power to sustain their impact has made men what they are. The great weapons have been the things of the mind, and among the greatest of these is knowledge.

' It is the duty of the Royal Society not to predict, not to legislate, but to maintain within the larger community the smaller one in which creative activity can flourish '.

Thus began with pomp and pageantry eight days of tercentenary celebrations. The events included lectures, receptions by universities and the City of London, showings of special films made by the Shell Co., excursions to industrial and university laboratories, a service at St. Paul's Cathedral, a conversazione at Burlington House and, finally, a banquet—bringing to a close a great festival of science.

NUCLEAR NOTES

Improved steels

New high-strength steels for high-temperature use in nuclear power reactors are being developed by Atomics International and U.S. Steel Corp. The development programme, conducted for the U.S.A.E.C., may lead to lower capital and operating costs and increased efficiency of nuclear power plants. It involves alloy modifications to low-cost chromium-molybdenum steels to increase their high-temperature strength and corrosion resistance to liquid sodium.

Concerned primarily with high-temperature sodium-graphite power reactor systems pioneered by Atomics International for the A.E.C., the project is being conducted at the company's nuclear field laboratory in the Santa Susana Mountains, 30 m. from Los Angeles.

Chromium-molybdenum steels possess good heat conduction properties and do not expand as much in the same temperature range as steels currently being used in the coolant piping of sodium-cooled power reactors. The pipes transfer liquid sodium from the core of the reactor to electrical generating facilities.

Available chromium - molybdenum steels, however, lack adequate strength during high-temperature operation of a sodium - cooled reactor. Liquid sodium leaving the reactor varies from 1,100 to 1,200°F.

Hydraulic cropping tool

Simple machine-shop operations become difficult when radioactive materials are being processed and, as a result, familiar pieces of equipment often have to be redesigned for use in atomic energy work.

Harwell engineers have had to design a new type of guillotine for shearing sheet metal. It is operated, in one application, inside a glove-box by a hydraulic ram under remote control.

In another, it is used—at the bottom of a deep stainless steel-lined tank filled with demineralised water—to cut the aluminium stems and noses from spent fuel elements from the DIDO and PLUTO reactors. These elements are highly radioactive and must be handled by remotely controlled equipment.

The guillotine was developed by Harwell for operation by a hydraulic device because all commercially available types were operated by long levers, precluding their use in glove-boxes.

The design is capable of modification to deal with bar metal.

Isotope information

The Isotope Information Bureau has been set up at the London Office of the U.K.A.E.A. to provide a convenient central point of enquiry for anyone seeking information on radioisotopes—their production and uses.

It will be of particular interest to managers, plant designers and production staff of those industries which have hitherto had little or no association with atomic energy but which nevertheless may secure considerable savings in their manufacturing costs by the application of radioisotopes to their factory processes.

The development of radioisotope applications is comparatively new, in consequence of which its techniques and practices are not widely known; for this reason display material has been set up in the windows of the Isotope Information Bureau explaining in non-technical terms what radioisotopes are, why they are made and their principles of operation when applied to industrial processes. Within the bureau a non-technical exhibition has been mounted describing examples of radioisotope applications to industry and the methods of packaging and distributing radioisotopes. In addition, a compact projector has been installed with which a short film can be shown to visitors describing actual radioisotope industrial applications.

Waste disposal

The release of highly radioactive wastes into the sea cannot at present be recommended as an operational practice, but the sea disposal of wastes of low and intermediate activity may be safe under controlled and specified conditions. This is one of the conclusions reached by an international panel of experts set up by the director-general of the International Atomic Energy Agency.

In convening the panel in October 1958, the director-general had taken into account a recommendation of the International Law Commission which, in one of the Articles concerning the Law of the Sea, had stated that I.A.E.A. 'should pursue whatever studies and take whatever action necessary to assist states in controlling the discharge or release of radioactive materials to the sea, promulgating standards, and drawing up internationally acceptable regulations to prevent pollution of the sea by radioactive materials in amounts which would adversely affect man and his marine resources'.

In its report the panel pointed out that the first principle must be the safeguarding of man against damaging effects of radiation, and only those waste disposal methods should be considered that do not involve any risk that is unacceptable either to the individual or to the population at large. In assessing the safety of proposed disposal operations, the most recent recommendation of the International Commission of Radiological Protection should be used as a guide.

Dubna conference

Scientists from 12 countries attended the eighth session of the scientific council of the Joint Nuclear Research Institute in Dubna, near Moscow.

In a report on the Institute's second five-year plan, its director said that the plan was based on further fundamental research into the physics of elementary particles and the atomic nucleus, with emphasis on the study of the structure of nuclear particles.

Prof. Wang Kang-chang, of China, reporting on the co-operation of the institutes and laboratories of the member-countries, said that special photo emulsion chambers, radiated in the synchrocyclotron, were being sent on to the institutes and laboratories of Bulgaria, Hungary, East Germany, China, Poland, Czechoslovakia and the U.S.S.R., whose scientists were studying the materials according to a single programme, this co-operation allowing them to cover a wide range of phenomena and to achieve more interesting results.

Prof. Wang said the latest in nuclear experimental techniques were the so-called bubble-chambers. They helped in obtaining thousands of photographs recording the traces of various nuclear reactions. Studies of these photographs by scientists of Dubna and the institutes of member-states were another field in which co-operation was developing.

V. Veksler, reporting on research at the high energy laboratory, said that in studying different types of collisions of high-energy particles by means of a proton-synchrotron, the physicists of the laboratory had obtained an unexpected result showing there was a certain uniformity in the behaviour of neutrons even in entirely different processes.

Sweden's research reactor

Sweden's fourth research reactor, the R2-O, went critical at the Atomic Energy Co.'s research station, Studsvik, south of Stockholm. It has a peak thermal effect of 100 kW. but will generally operate at about 5 W.

The reactor is the 'baby brother' of the R2 materials-testing reactor at Studsvik and will use the same pool. It will primarily be used for irradiation protection tests and for preparing experiments with the R2.

The new unit has been delivered by Asea, Vasteras, and is the first complete reactor to have been built by a Swedish company on normal commercial terms. It was completed in 12 months and has cost about Kr. 1.5 million (£103,000). When going critical, the reactor had a core of 28 fuel elements with a total uranium content of 3,356 g. of U^{235}.

Power requirements

'The long-term need for atomic energy as a source of power remains as great as ever', states the annual report of the I.A.E.A. to the U.N. Economic and Social Council. 'If there has been some deferment of short-term expectations', the report points out, 'it is probably because earlier appraisals underestimated the seriousness of the technological problems and were unduly influenced by transient economic and political factors'.

The report, covering the period April 16, 1959, to April 15, 1960, says that a solution of the practical problems involved in developing the technology of nuclear power will depend on progress in quite separate branches of science and industry. Advances in metallurgy or electronics in the next few years could, for example, result in important economies in nuclear power generation, and it is possible that the cost of nuclear fuels will fall. In the meantime, the Agency is helping its member states in preparing for the eventual introduction of nuclear power by economic and technical studies, by giving technical assistance to basic atomic activities, by exchange of information through scientific meetings and publications, by training personnel, and by formulating measures to ensure safety in the atomic industry.

Under the present programme, studies are being made of different types of power reactors, particularly with reference to their costs and technical performance, and of the special requirements for reactors for use in the less developed areas of the world.

The number and variety of requests for technical assistance has exceeded expectations, and at present the Agency is meeting requests from 23 countries for 65 experts and supplying equipment to 17 countries. Requests for the services of 32 field experts were approved last year; by the end of June six of them will have completed their assignments, while most of the others will be in the field. Request for equipment and technical supplies, valued at a total of U.S. $125,000 were approved last year; under this year's programme requests have been received for equipment and supplies worth about U.S. $500,000.

FUEL-HANDLING CASK

Giant fuel-handling cask developed by Atomics International for the U.S. Atomic Energy Commission is being tested at the company's nuclear field laboratory near Los Angeles. The 54-ft.-high machine will handle and load reactor components 40-ft. long for A.E.C.'s Hallam nuclear power facility in Nebraska. It will be dismantled and shipped to the reactor site next February.

Organic moderators

The U.S. Atomic Energy Commission has authorised the Fluor Corporation Ltd. to perform architect-engineering services in conjunction with the modification of the Organic Moderated Reactor Experiment at the National Reactor Testing Station near Idaho Falls.

The experiment was originally designed to test the feasibility of a nuclear power reactor cooled and moderated by an organic fluid. Successful operation of the reactor has indicated a need to continue engineering development of this concept. The modification will extend the operating usefulness of the facility over the next few years. The total cost of the project will be over $1 million.

Solution type reactor

A nuclear research reactor operated by Atomics International, KEWB, for the U.S. Atomic Energy Commission, has reached a power peak of 2.3 million thermal kW. after installation of a new core vessel.

The reactor is a 50,000 W. homogeneous reactor fueled with a solution of uranium-235. It was designed and built by Atomics International to conduct reactor safety studies. The reactor is operating at the company's nuclear field laboratory near Los Angeles.

Quick surges of energy are produced to investigate basic mechanisms and the inherent shutdown behaviour of the reactor during abnormal operating conditions. The pulse reactor also can be used for determining the effects of intense momentary radiation on biological systems and electronic equipment.

Company News

Polyisoprene

Shell Chemical Co. division of Shell Oil Co. U.S.A. is to increase its production of polyisoprene (natural-synthetic rubber) to 120 million lb. p.a.

This increase in capacity will involve construction at a mid-western location of an integrated monomer-polymer plant of 80 million lb. p.a. capacity. Hydrocarbon feedstocks for the plant will come from the company's Wood River refinery.

Polyisoprene has been manufactured commercially on a scale up to 5 tons/day at Torrance, Calif. This plant is at present being expanded to a capacity of 40 million lb. p.a. with completion of construction expected this autumn. The mid-west installation, which is in an advanced stage of engineering design, will be on stream one year later.

Gas meter testing

Parkinson Cowan (Metropolitan Leather Co. Ltd. division) are shortly to open a new gas meter diaphragm testing and research laboratory at their Great Harwood factory.

Included in the company's research programme are continued investigations into the use of polymer as diaphragm material.

Increasing chlorine production

An increase in chlorine production of 50% at its Elworth, Cheshire, works is planned by Murgatroyd's Salt & Chemical Co. Ltd., the jointly-owned subsidiary of Fisons Ltd. and the Distillers Co. Ltd. The new plant will cost about £1.5 million and is scheduled to come into production in the latter half of 1961.

Project managers for the expansion are the D.C.L. Engineering Division, and main contractors for the plant construction and installation are W. J. Fraser & Co. Ltd. Bernard Taylor & Associates are the architects.

Acetic acid plant

The Distillers Co. Ltd. chemical division is to construct a new acetic acid plant at its chemical factory in Hull at a cost of about £2 million. This plant will be the first of its kind in Europe. It will use a new process developed by the company's research and development department, based on the direct oxidation of a light petroleum fraction. It is expected that the new plant will be in operation early in 1962, when a proportion of the company's output of acetic acid will be made by this process.

The company at present produces acetic acid in a two-stage process from ethyl alcohol. The alcohol is first dehydrogenated to acetaldehyde, which in turn is oxidised to acetic acid.

Superphosphates

A £1 million extension to the Fisons Fertilisers Ltd. factory at Immingham will enable the production of phosphoric acid to be stepped-up from June 1961.

Ammonium phosphate will also be manufactured for the first time following modifications to a plant now producing triple superphosphate. It will be distributed to the company's fertiliser plants throughout Britain, where it will be used in the manufacture of high analysis compounds.

These modifications should lead to greater efficiency in manufacture and also enable the farmer to be provided with fertilisers of higher plant food concentration.

Scottish firm expands

Henry Balfour & Co. Ltd., gas and chemical engineers of Leven, Fife, are to proceed with a major expansion of manufacturing facilities. They will build a new 24,000 sq. ft. boiler shop, costing £250,000, and other ancillary units, costing in all £500,000. This development at Mountfleurie will supplement the older Durie Foundry works, where expansion and development plans are also in hand. A very big extension to the enamelled products department has been approved and other development will be tackled at Durie.

Ammonia plant

A 300 ton/stream day ammonia plant and all off-site facilities will be designed and constructed near Joplin, Missouri, U.S.A., for Solar Nitrogen Chemicals Inc. by the M. W. Kellogg Co. The new plant will be designed to use the Kellogg steam methane reforming process, as was the 300 ton/stream day plant constructed in 1955.

Solar Nitrogen Chemicals Inc. is owned equally by Standard Oil Co. (Ohio) and Atlas Powder Co. Atlas will operate the new plant and Sohio Chemical Co. will market the product. Construction will begin soon and completion is expected in one year. The new plant will produce anhydrous ammonia from primary raw materials comprising natural gas, steam and air.

Phenol plant in Kentucky

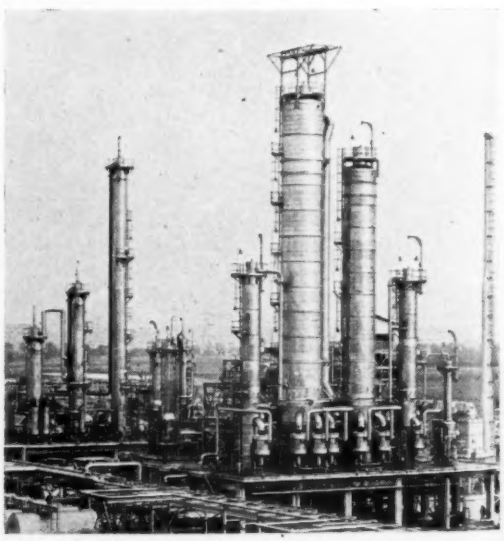
Hooker Chemical Corporation are to build a new multi-million dollar plant in northern Kentucky to produce synthetic phenol.

Construction of the plant will begin later this year with completion anticipated by the end of 1961. Other facilities for this site are in the preliminary planning stage.

The new Hooker phenol process will be used. This process is the result of research and development work on the Raschig process now utilised by the Durez Division at its North Tonawanda, N.Y., plant.

STYRENE

A styrene monomer plant built recently for Shell Chemical Co. Ltd. at Carrington, near Manchester. Procurement and erection were entrusted to Matthew Hall & Co. Ltd.



Orders and Contracts

Deaerators

William Boby & Co. Ltd. have been awarded a contract valued at £40,000 by Parolle Electrical Plant Co. Ltd. for five deaerators for Richard Thomas & Baldwins Ltd.'s Spencer Works.

Radiation monitoring

Ekco Electronics Ltd. have received an order from the Central Electricity Generating Board for 86 radiation monitors. They will be used at the Board's new nuclear power stations at Berkeley, Bradwell and Hinkley Point and are all portable, battery-operated instruments.

Atomic consortia join forces

As a result of further discussions between Atomic Power Constructions Ltd. and the General Electric Co. Ltd.-Simon-Carves Atomic Energy Group these companies have now agreed to join forces to design and build nuclear power stations in this country.

Gasholders

Instructions to proceed with work on gasholder contracts with a value of about £1 million have recently been received by P.G. Engineering Ltd. from clients in the U.K. and overseas. The most recent contract received is for a 3 million cu.ft. *A.B.P.-Klonne* type gasholder to be installed at John Lysaght's Scunthorpe Works Ltd. This holder will store blast-furnace gas and is planned for completion by the end of 1961.

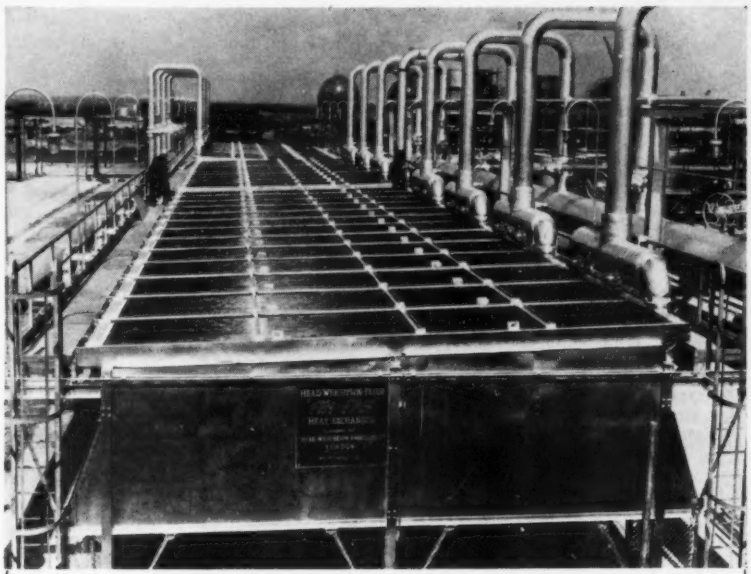
R.T.B. Ltd. have also ordered two *A.B.P.-Klonne* gasholders from the company's associates, Ashmore, Benson, Pease & Co. Ltd., and P.G. Engineering will carry out this work. One holder will store 5 million cu.ft. of blast-furnace gas, and the second 2 million cu.ft. of coke-oven gas, at the new Spencer Works.

Five column-guided gasholders to serve a large fertiliser factory in India are also included in the recent contracts. One holder is to have a capacity of 15,000 cu.m. and each of the other four 5,000 cu.m.

Fans and motors

The London Fan & Motor Co. have acquired the total share capital of Batwin Electric Motors Ltd.

This further expansion comes at a time when the factory of the London Fan & Motor Co. is being extensively reorganised and re-equipped.



AIR-COOLED HEAT EXCHANGERS

Head Wrightson Processes Ltd. have received an order worth about £55,000 from the Iraq Petroleum Co. for Fin-Fan *air-cooled heat exchangers. The units are to be used to cool lubricating oil from gas turbines at two pumping stations in Syria. Five large coolers will be kept constant automatically with varying heat load and ambient conditions.*

Vegetable oil mills

Rose Downs & Thompson Ltd., a member of the Power-Gas group, has received a contract valued at about £160,000 from Kenya for a complete plant to recover crude pyrethrin extract from pyrethrum flower heads.

The same firm has received two contracts valued at nearly £200,000 for complete vegetable oil mills, both of which incorporate refining and deodorising equipment. The first mill is to be erected in West Africa and will incorporate four *Rosedowns* 'long-cage' *Maxoil-Duplex* high-pressure expellers and one 'long-cage' pre-pressing expeller.

The other mill, destined for the West Indies, will process 40 tons/day of oilseeds in two 'long-cage' expellers.

Direct-arc melting furnace

A contract has been placed with Birlec-Efco (Melting) Ltd. by Electro Metallurgical Works Private Ltd. for a special direct-arc melting furnace. It is to be installed at Dandeli, in the state of Mysore, India. Arranged for 90° nose tilt, the furnace will be hydraulically tilted.

Rated at 1,200 kVA., the plant will be used for the production of ferro-manganese. Some of this material, which is used as an alloying element for steel, will be supplied to the new Durgapur steelworks for use in the production of special steels.

The total value of the order is about £40,000.

Thermonuclear laboratory

A building contract for the first phase of construction work at the U.K.A.E.A.'s new research establishment at Culham, Oxfordshire, has been awarded to Messrs. Gleeson.

The Culham site is to be developed as a laboratory for research into controlled thermonuclear reactions and plasma physics. The first batch of buildings to be erected on the site will accommodate the large facilities needed for the intermediate current stability experiment and its associated services. Buildings will be added within the next two years to accommodate the remainder of the research being transferred to Culham.

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Personal Paragraphs

★ **Dr. P. Fortescue** has been appointed chief research and development engineer of the newly organised General Atomic Europe. He is chief research and development engineer of General Atomic Division of General Dynamics Corporation in San Diego, Calif., U.S.A., and will also continue to act in that capacity.

★ **Sir Ralph Sorley,** K.C.B., O.B.E., deputy chairman and managing director of de Havilland Propellers Ltd. and a director of de Havilland Holdings Ltd., retired at the end of June. He is succeeded as managing director of the propeller company by **Mr. H. G. Sturgeon,** O.B.E., who has been deputy managing director for the past three years.

★ **Mr. J. J. Gracie,** C.B.E., a director of the General Electric Co. Ltd. and general manager of its Witton Engineering Works, is to retire at the end of this year after 34 years' service with the company.

★ **Mr. B. Wright,** of John Thompson Instrument Co. Ltd., who joined the company in June 1958 as their London representative, has been promoted to the position of sales manager.

★ **Mr. C. R. Prichard,** director in charge of the I.C.I. Heavy Chemicals Group, has resigned due to ill health. He joined Brunner, Mond & Co. Ltd. in 1926 as a chemist and, after serving in various executive capacities in the alkali and salt divisions, was appointed a director of the company in 1952.

★ **Mr. E. R. Angel** has been appointed a non-executive director of Albright & Wilson Ltd. He is chairman and managing director of Star Paper Mills Ltd. and a director of other companies.

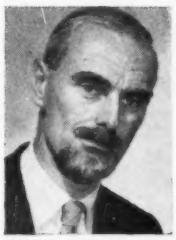
★ **Mr. J. A. Harvey** has resigned as general sales manager of the chemical division of the Distillers Co. Ltd. and **Mr. R. M. F. Fenning** (formerly marketing manager) has been appointed in his place.

★ **Mr. T. H. Cook** has been appointed chief applications engineer of the Morgan Crucible Co. Ltd. He was previously carbon department sales promotion manager.

★ **Dr. H. Hookway** has been appointed director of the U.K. Scientific Mission in Washington, D.C., and Scientific Attaché at the British Embassy there. He will succeed **Mr. E. S. Hiscocks,** who is returning to Britain in the autumn on completion of a three-year tour of duty to become director of the Tropical Products Institute. Dr. Hookway is the assistant director of the National Chemical Laboratory, where he has been since joining the D.S.I.R. in 1949. He is well known for his work on polymers, ion-exchange resins and saline water conversion.

Mr. B. Wright.

Mr. R. Miles.



Dr. P. Fortescue.

Dr. N. de Bruyne.

★ **Mr. R. Miles,** who retired as chairman and managing director of Head Wrightson at the end of January, has recently been given a presentation to mark his retirement by the board, staff and work people at the head office in Thornaby. He joined the company in 1932 and was chairman and managing director for 10 years.

★ The death occurred in June of **Mr. J. Jones,** director of the Laporte Industries Ltd. and also chairman and director of Laporte Acids Ltd., the Sheffield Chemical Co. Ltd., James Wilkinson & Son Ltd. and Glebe Mines Ltd. He was also a member of the Council of the National Sulphuric Acid Association and chairman of the Yorkshire Section.

★ **Mr. J. F. Perkins,** a member of the Pyrethrum Board of Kenya since 1956, has been elected vice-chairman. The board markets the Kenya pyrethrum flower crop, from which is derived a powerful insecticide. He was formerly general manager of the Magadi Soda Co., Kenya (an I.C.I. subsidiary). He replaces **Mr. R. T. Mytton Watson,** who resigned in March.

★ **Mr. W. E. A. Redfearn** has resigned as chairman of the Alloy Steels Association and is succeeded by **Mr. R. Bavister.** Mr. Redfearn is a director of English Steel Corporation Ltd., English Steel Rolling Mills Corporation Ltd. and managing director of English Steel Forge and Engineering Corporation Ltd., and has been chairman of the Alloy Steels Association for 10 years. Mr. Bavister is a director and commercial manager of Samuel Fox & Co. Ltd.

★ **Mr. J. C. Nutter** and **Mr. R. Y. Parry** have joined the board of Isotope Developments Ltd., a member of the Elliott-Automation Group. Mr. Nutter is a director of Elliott Nucleonics Ltd. and Mr. Parry, who has been with Isotope Developments for a number of years, is the manager of the company's works near Aldermaston.

★ **Mr. L. P. Simpson,** works manager of Baker Perkins Ltd., has been appointed a director. He joined the company as assistant works manager in 1951.

★ **Dr. N. A. de Bruyne** is to resign from the position of managing director of Ciba (A.R.L.) Ltd. at the end of this year, but will remain on the board. His resignation is due to a wish to devote more time to research, especially to the development of scientific instruments. He is founder of the company. **Mr. R. F. G. Lea,** O.B.E., will become deputy chairman of the company and joint managing director. The other joint managing director will be **Mr. D. A. Hubbard.**

★ **Dr. A. Caress,** chairman of I.C.I. Ltd. fibres division since its formation in 1956, has been appointed a director of the company. **Mr. G. F. Whitby,** a managing director of the fibres division, has been appointed chairman in his place. **Dr. E. B. Abbot** has been appointed a fibres division managing director.

World News

NEW ZEALAND

Oil refinery investigation

A team of technical experts from Delft University, Holland, will arrive in Auckland soon, to carry out investigations in connection with the proposed New Zealand oil refinery.

To test the suitability of land for foundations, the visitors will work with Ministry of Works men and equipment. Their first investigations will be made at Matingarahi, on the Firth of Thames, south of Auckland, the most favoured site for the refinery.

Subsequently they are expected to visit Marsden Point, near the south head of Whangarei harbour, Northland, which has been named as a possible site.

INDIA

Lime and dolomite plant

The lime and dolomite plant at the Durgapur Steelworks has just been completed and is now in operation. Limestone is one of the raw materials used for steel-making in the open hearth furnaces. The furnaces will use both limestone and burnt lime, the latter speeding up the process. Burnt dolomite is used for fettling the furnace lining after each tap.

The plant consists of two vertical shaft lime kilns, each capable of producing 75 tons/day of burnt lime. The kilns are fired by a mixture of blast furnace and coke oven gases. The burnt lime is discharged from the bottom of the kilns and transferred by vibrating feeder and conveyor belt to the storage bunkers.

The dolomite burning plant consists of a horizontal kiln 275 ft. long with a diameter of 8 ft. 6 in. It is continuously charged with raw dolomite and iron oxide. After passing through the kiln, the burnt dolomite is discharged into a rotary cooler 65 ft. long and then crushed before transfer to the storage bunkers by conveyor belt.

ITALY

New resins produced

Laboratori Italiani Ricerche Chimiche, L.I.R.C. of Milan, Italy, jointly owned by Ledoga S.p.A. and Snia Viscosa, has developed two new resins with higher temperature resistance than either polystyrene or acrylates. Named *Dialux* A and *Dialux* C, they are derivatives of itaconic acid, a product of sugar fermentation. They are expected to find use as glass substitutes. They will be fully described in a paper to be presented at the American Chemical Society National Convention in Cleveland.

UNITED STATES

Desalting unit

A very large brackish water desalting unit was recently opened by the City of Oxnard, Calif., U.S.A., and Ionics Inc., who designed and built the equipment.

The unit, installed near the city's main water production plant, is removing over half a ton/day of excess dissolved salts and minerals from 250,000 gal./day of Oxnard's highly mineralised municipal well water. The total cost of this demineralisation is about 20 cents/1,000 gal. or $65/acre ft.

In the last 25 years total dissolved mineral content of the well water has increased from 870 to more than 1,300 p.p.m. Recently the rate of increase of mineral content has accelerated to about 6% p.a., due to mineral deposits left deep in the ground by ancient seas, salt build-up resulting from intensive irrigation and fertiliser use in the rich farming area surrounding the city, and sea-water intrusion. The new desalting unit is reducing total dissolved mineral content of the 250,000 gal./day of water by about 40%. It is therefore reducing 1,300 p.p.m. to a little less than 800 p.p.m., well below the preferred maximum U.S. Public Health Service standard of 1,000 p.p.m.

Isocyanate production

Plans to more than triple the production of isocyanates have been announced by Allied Chemical.

The expansion will necessitate a multi-million dollar investment in new construction and equipment at Moundsville, Va. Construction of new facilities will begin immediately and will be completed in mid 1961.

Markets currently under rapid development involve the use of polyurethane elastomers and isocyanate-based clear varnishes and other coatings for industrial maintenance.

EUROPE

Review of coal situation

The gravity of the coal situation, caused by the excess of supply over demand, is emphasised in the Annual Report of the O.E.E.C. Coal Committee published under the title 'The Coal Industry in Europe'. The glut on the coal market, which has lasted for more than two years, is in sharp contrast with the shortage which, with a few brief exceptions, was felt from 1945 to 1957. This sometimes acute shortage and its persistence had led to the conclusion that one of the features of the energy economy of the Western European countries in the next 15 to 20 years would be a steady increase in coal requirements. In the two years 1958 and 1959, the apparent coal consumption of O.E.E.C. member countries fell by about 62 million tons, or nearly 6% p.a.

The Coal Committee believes that the present recession in coal is no doubt due to structural factors, although associated cyclical factors connected with the 1958 recession and exceptional climatic conditions have certainly helped. According to calculations made by the Secretariat, the fall of 38 million tons in the demand for coal in 1958 can be explained by the recession in industrial activity (11 million tons), the switch from coal to oil (12 million tons), higher fuel efficiency (6 million tons), the mild winter (5 million tons) and exceptionally good hydro-electric conditions (4 million tons).

SWEDEN

Acetic acid plant

A Stockholm firm, A. B. Chematur, has concluded a contract with two Indian enterprises for the delivery of plants for the production of acetic acid.

Each of the contracts is worth about Kr. 2 million (£140,000).

The two plants are scheduled for a production of 10 tons/hr. of acid. The Indian customers are Andhra Sugars Ltd., near Madras, and Indian Organic Chemicals, Bombay.

ARGENTINA

Polyethylene project

Industrias Quimicas Argentinas 'Duperial' S.A.—a subsidiary of I.C.I. Ltd.—is to build a plant to manufacture polyethylene. The plant, which will be financed by the parent company, will cost £5.75 million. It will have an initial capacity of 10,000 tons p.a. and will be built on the outskirts of San Lorenzo.

Duperial will use the I.C.I. Ltd. high-pressure polymerisation process based on ethylene. They will obtain their raw material by cracking an indigenous light petroleum distillate.